EE 5220 - Lecture 12 Friday Feb 4, 2022

Topics for Today:

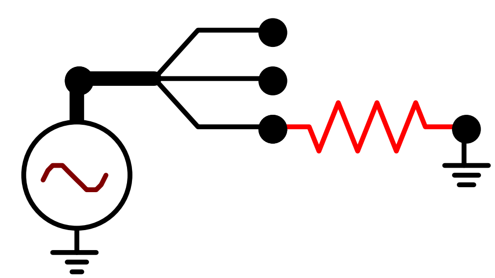
- Startup
  - Web page: https://pages.mtu.edu/~bamork/ee5220/
  - Software - Matlab. ATP/EMTP [License - www.emtp.org]
    ATP tutorials posted on our course web page
  - EE5220-L@mtu.edu (participation = min half letter grade)

- HW#4 parameters soon posted. Partnered exercise. Due Tues Feb 15^{th}
- ATP Simulation pointers
- Cap Bank Switching (continued)
  - Circuit Breaker ratings - Capacitive Switching
  - Parameters
    - Cap Bank configurations
    - Current Limiting Reactors
- ATP - how it works internally
  - Conductance matrix formulation
  - Rs, Ls, Cs
  - Transmission lines

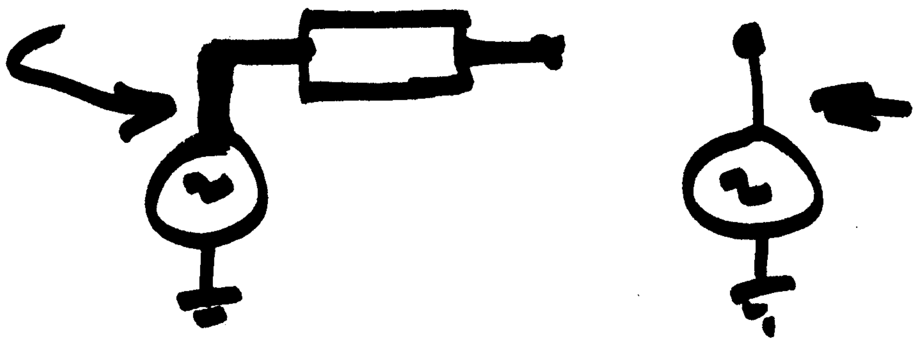
ATP Simulation Pointer for the day:

When building 3-phase circuits, you are actually drawing a one-line which represents the L-G per-phase equivalent of the system. Node names have a base name 5 characters long, with the 6th character A, B, C automatically added. Click on the 3-phase end of the splitter if you want to define the base node name.

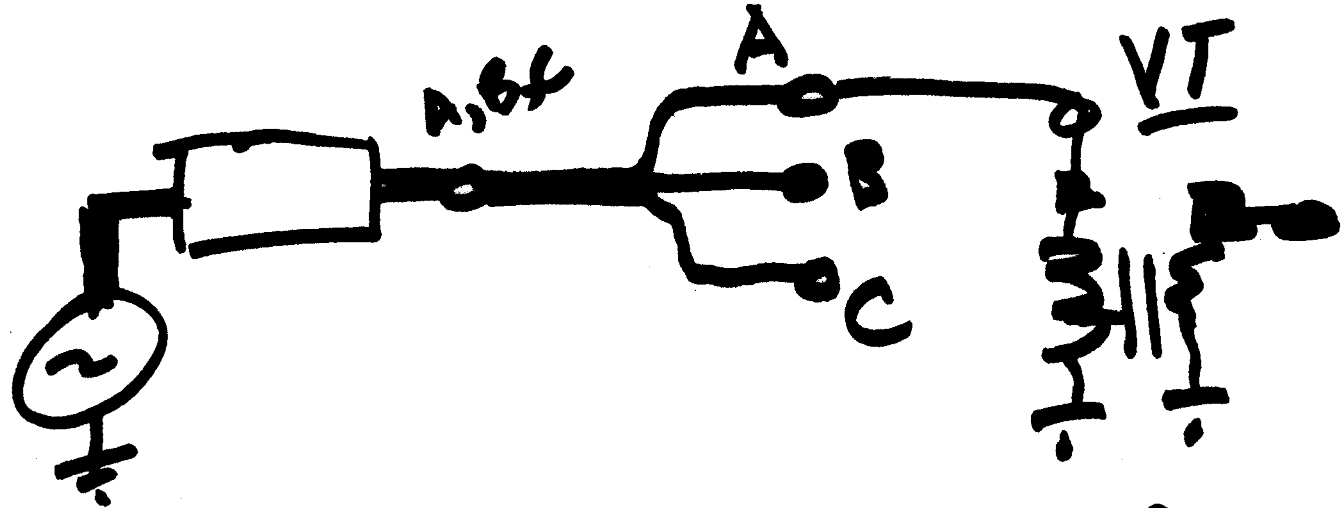
If you need to make single-phase connection(s) to individual phases, use the splitter. When drawing a connecting line to a splitter, start at the node of the single-phase element and connect ***to*** the splitter. If you need to ground one phase, you can do that at the single phase element, but not at the splitter.



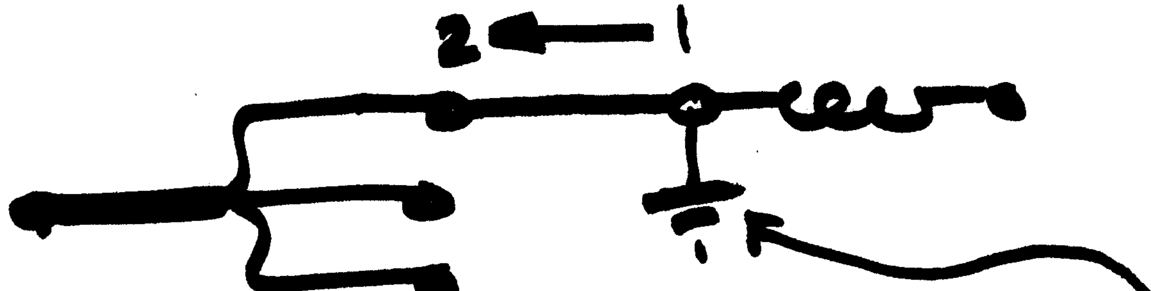
3-PHASE ELEMENTS



SPLITTER · 3ph → 1ph



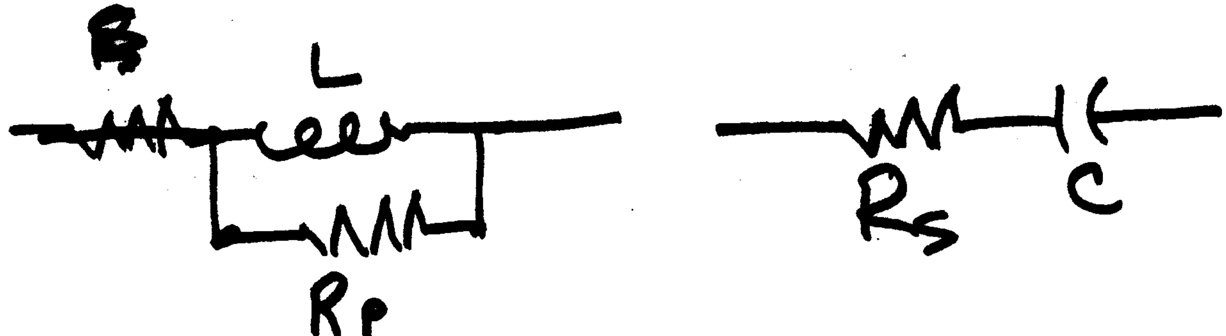
CONNECTING: Draw from 1→2



Ground - Connect at 1φ element

ATP Simulation Pointer for the day:

What are the best values of numerical damping resistances to add to small L's and large C's? This turns out to be a function of the integration timestep and the value of the L or C.



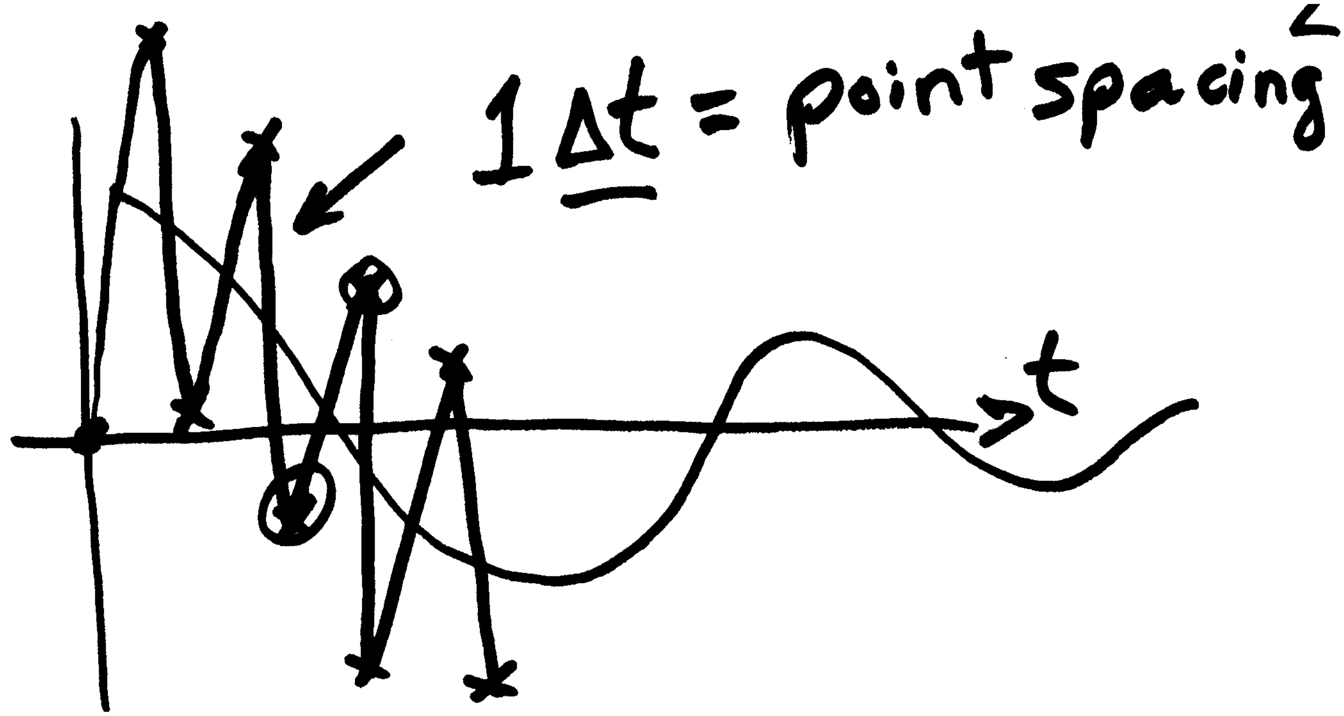
"EMTP Theory Book"

$$R_p = \frac{2L}{0.15\,\Delta t}$$

$$R_s = \frac{0.15\,\Delta t}{2C}$$

$K_p \cong 7.5 \cong \frac{1}{0.15}$

$K_s \cong 0.15$

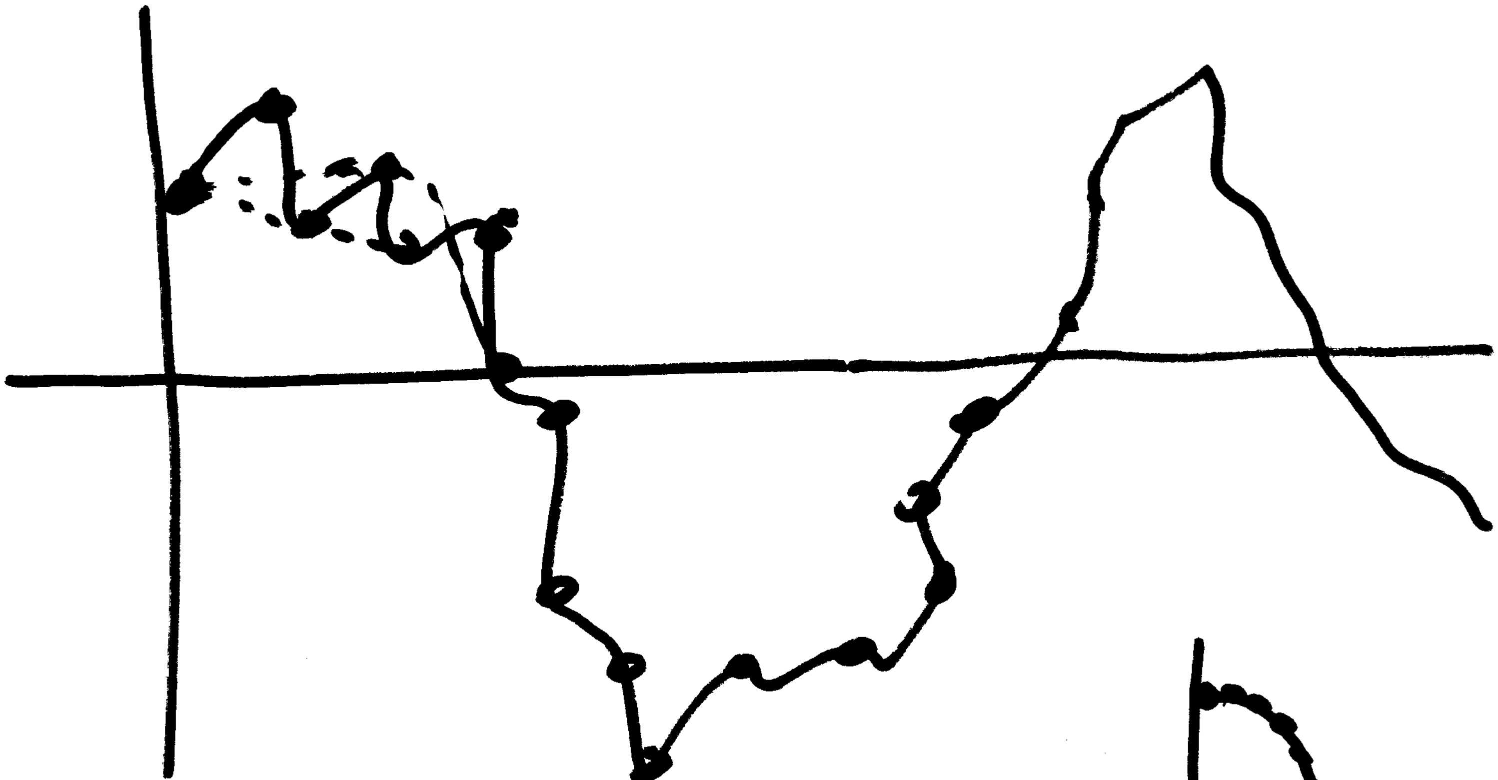


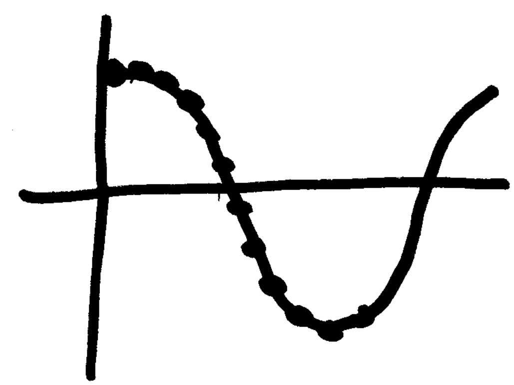
Key: Look at ATP Settings
Set Integer Parameter
"Plot Freq" = 1

(often set to larger <u>odd</u> number to reduce PL4 file size).

Be careful of aliasing errors! Use odd number, and not too large!

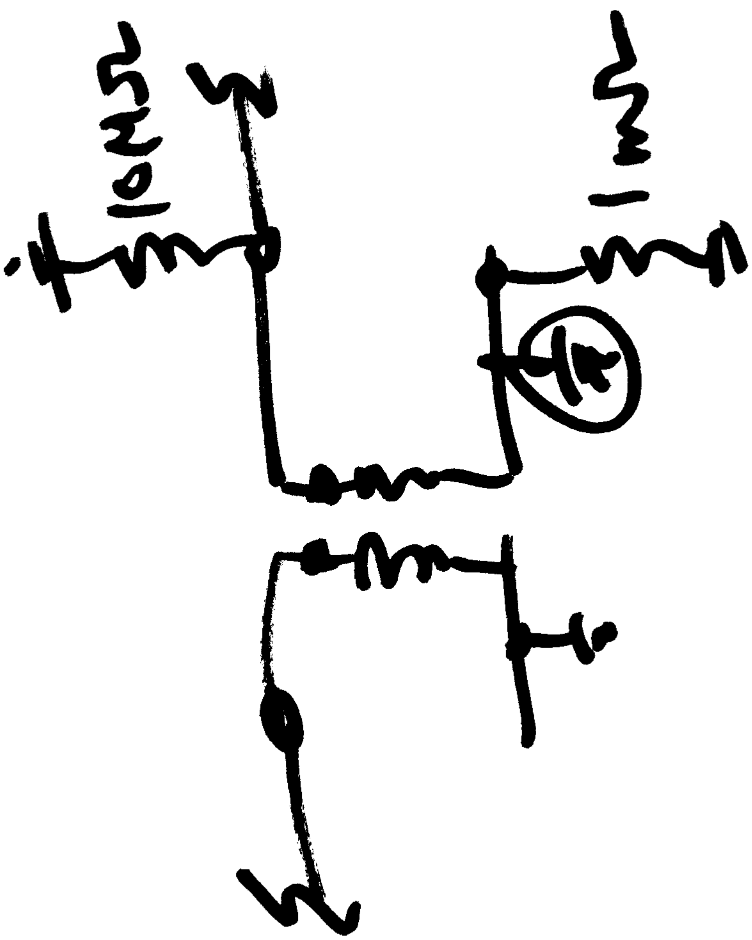
*.lis = text log   *.pl4 = binary plot





aliasing error

- always skip _odd_ # pts.



Current-Limiting Reactors (CLRs)

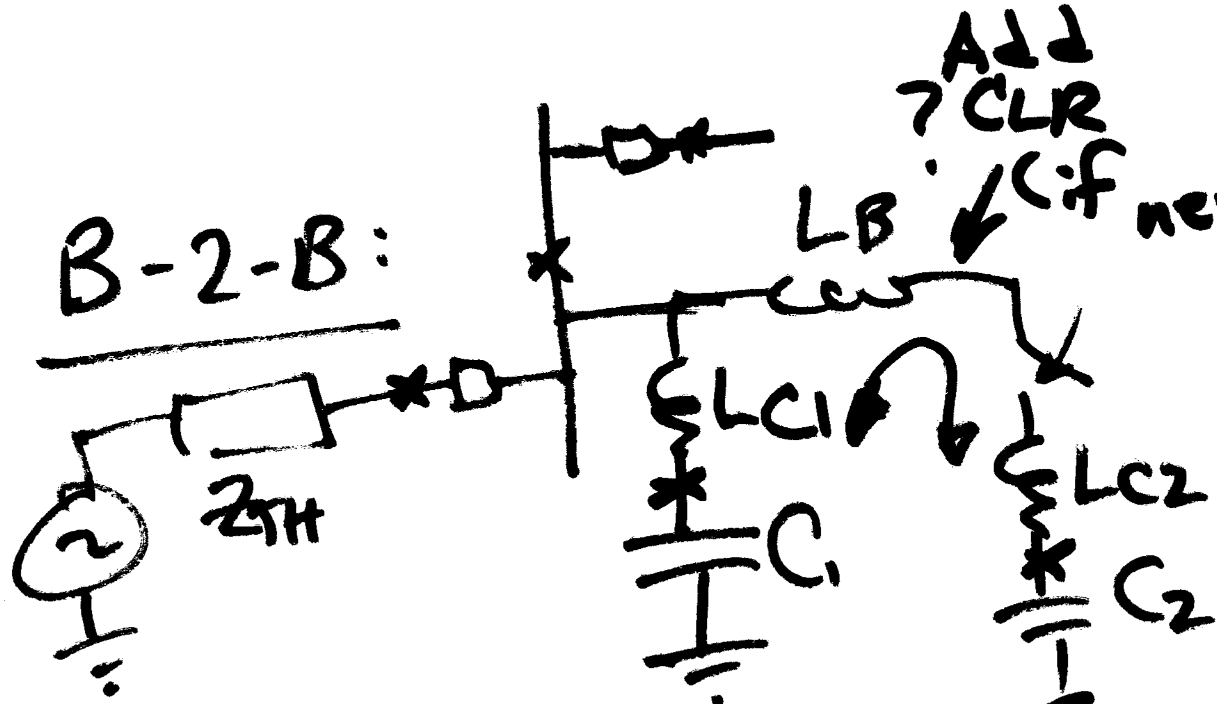
- Back-to-Back Switching
- Outrush

$I_p \times f_0 \leq$ ________ A·Hz

Gen : 2×10^7

Def : 6.8×10^7

B-2-B:



$L_{EQ} = L_{C1} + L_B + L_{C2}$

$C_{EQ} = \frac{C_1 C_2}{C_2 + C_1}$

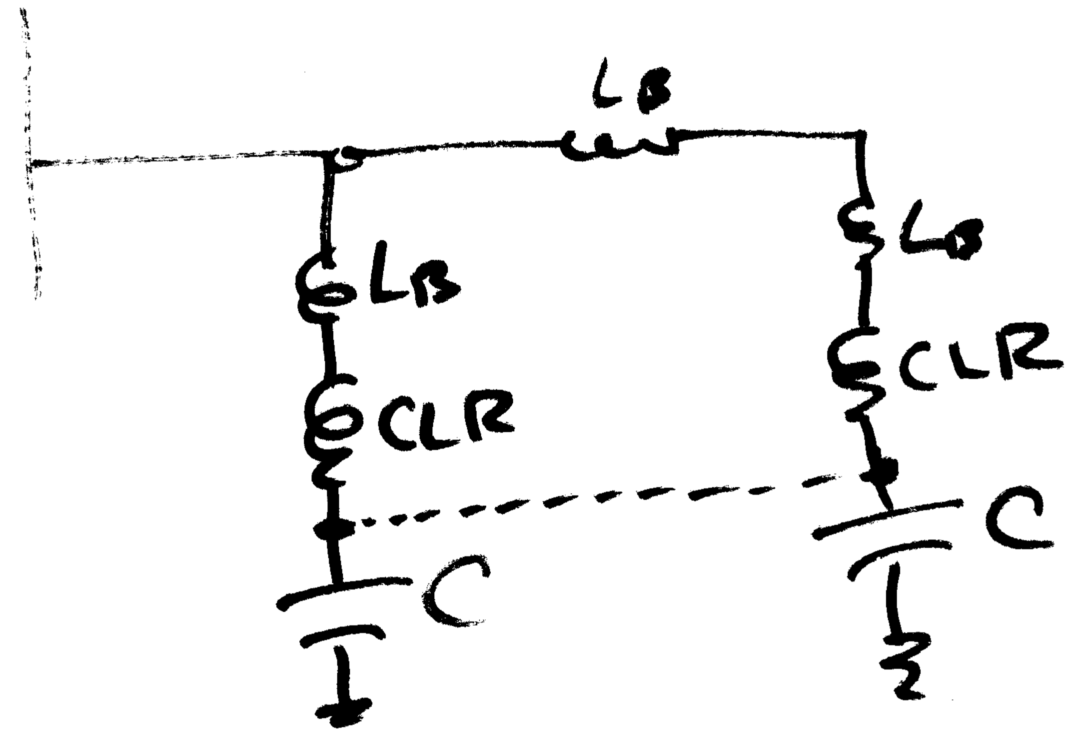
$$I_p = \frac{V_p}{Z_o}$$

$$V_p = \frac{34{,}500}{\sqrt{3}}\sqrt{2} = 28.1\text{ kV}$$

$$f_o = \frac{1}{2\pi\sqrt{L_{EQ}C_{EQ}}}$$

$$I_p f_o = \frac{V_p}{Z_o} \cdot \frac{1}{2\pi\sqrt{LC}}$$

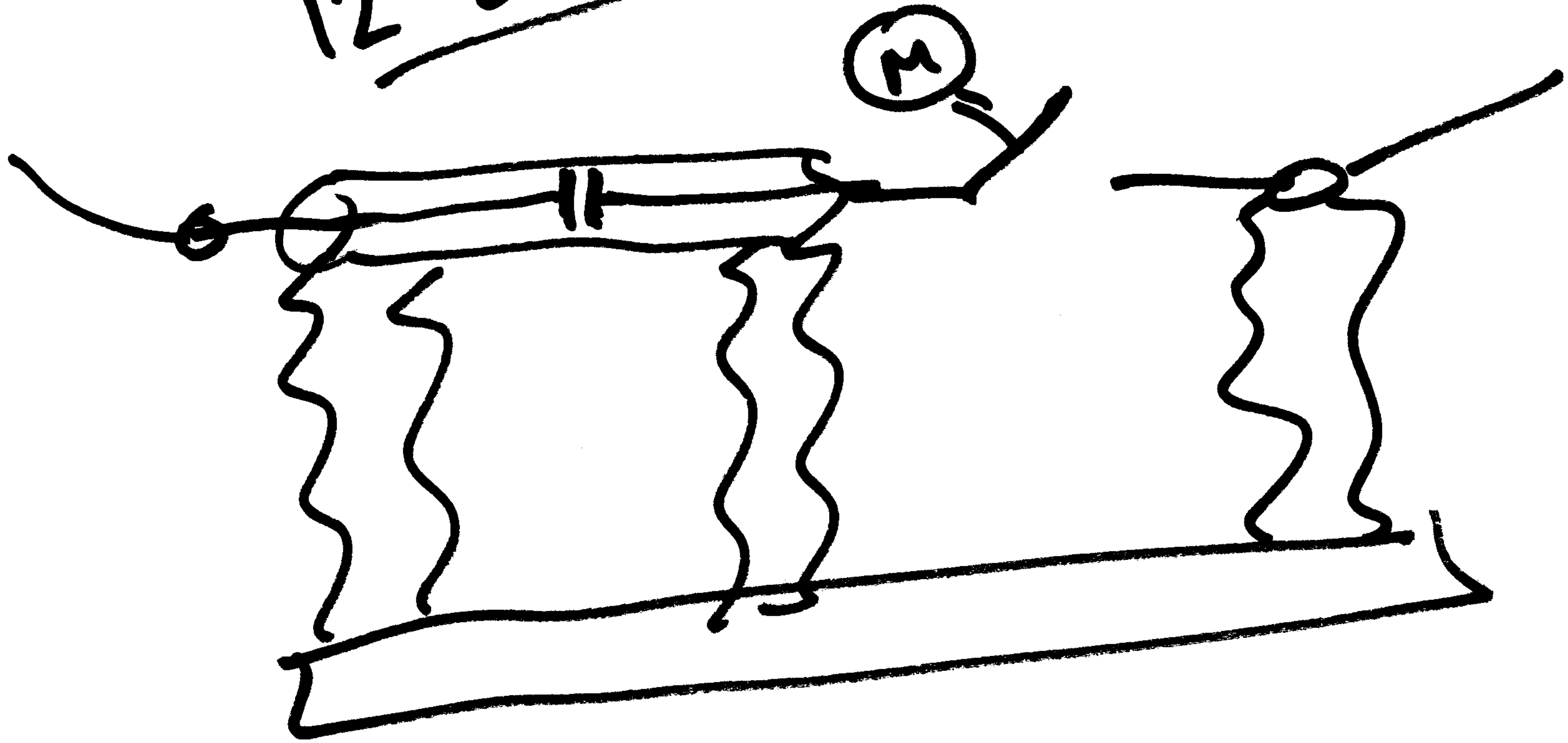
$$I_p f_o = \frac{V_p}{\sqrt{\frac{L_{EQ}}{C_{EQ}}}} \cdot \frac{1}{2\pi\sqrt{L_{EQ}C_{EQ}}} = \boxed{\frac{V_p}{2\pi L_{EQ}}}$$



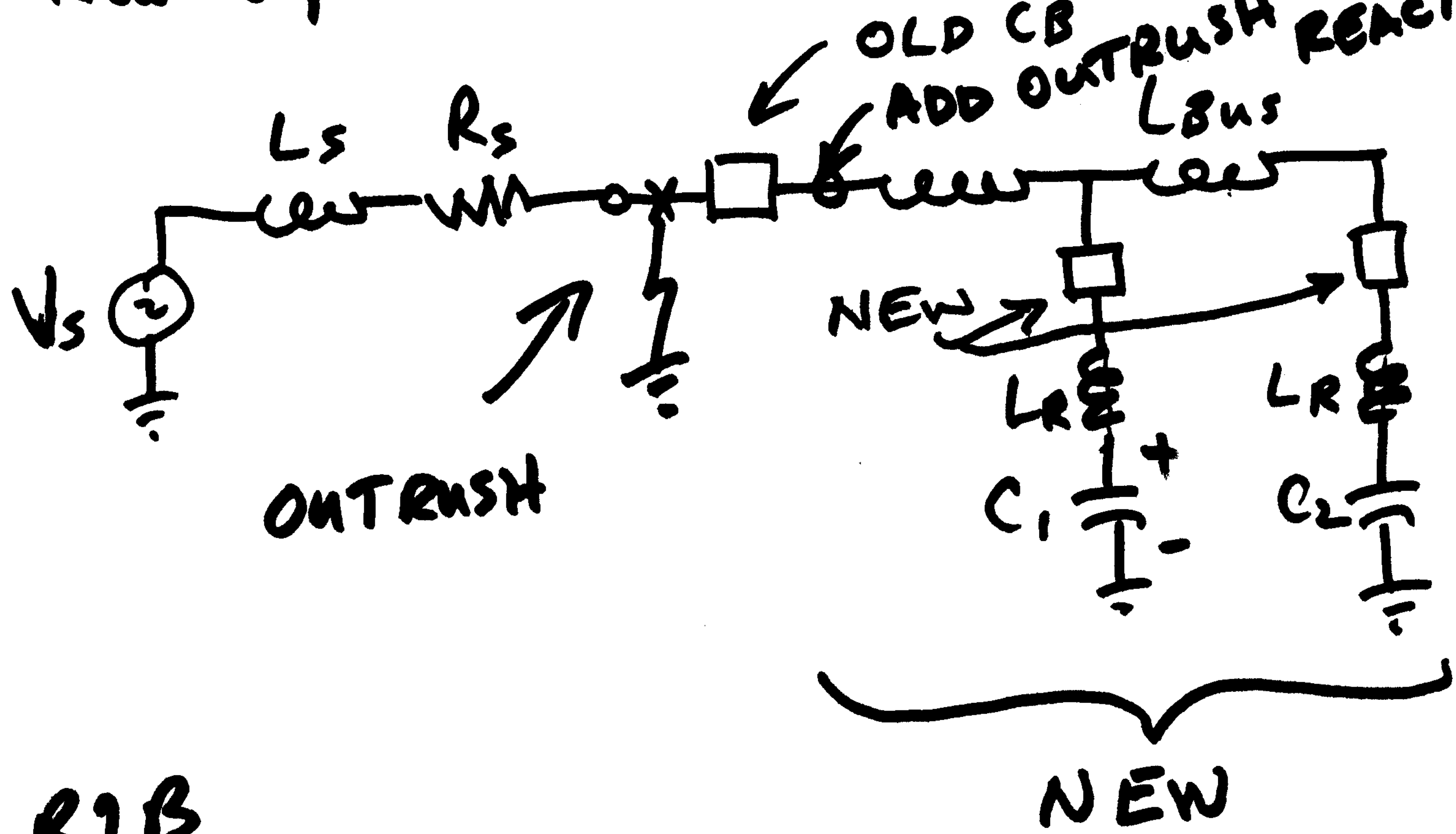
$$CLR_{\text{Parallel Banks}} = Np \times CLR_{\text{single bank}}$$

Circuit Switcher

12-20 kA



New Cap Installation –



B2B

Add current limiting reactors

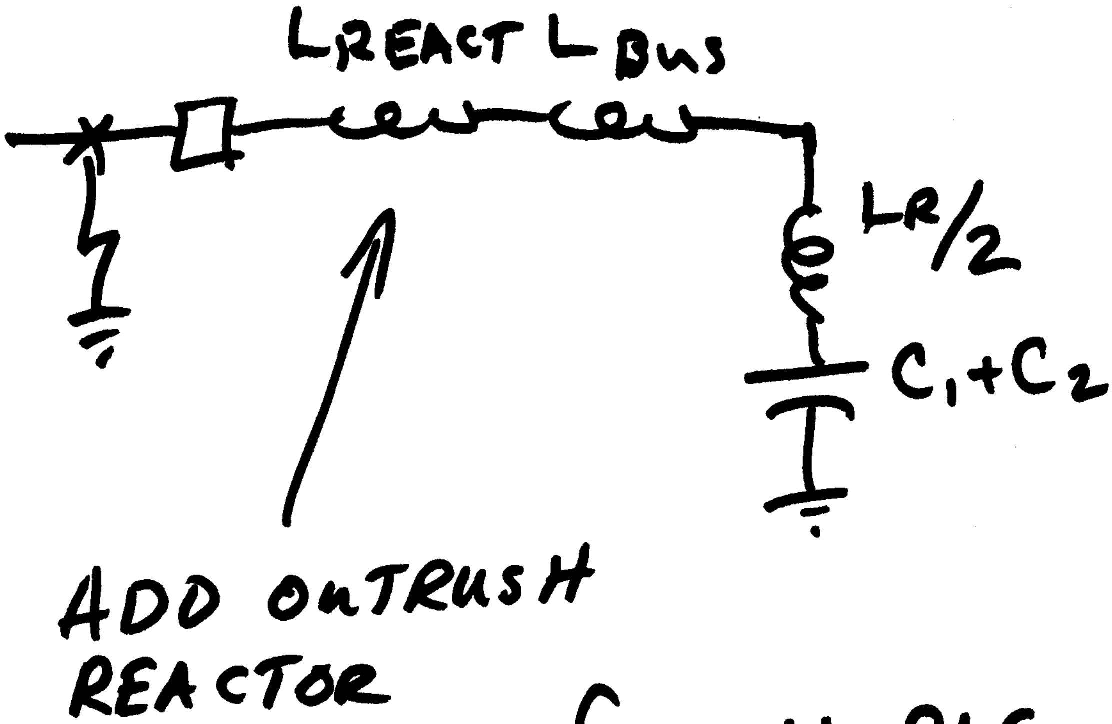
$$\omega_0 = \frac{1}{\sqrt{(L_{Bus}+2L_R)\left(\frac{C_1 C_2}{C_1+C_2}\right)}}$$

$\therefore$ ω_0 decreases.

$$Z_0 = \sqrt{\frac{L_{Bus}+2L_R}{\frac{C_1 C_2}{C_1+C_2}}} \Rightarrow Z_0 \text{ increase}$$

GREAT!

CB's are rated in terms of $\boxed{I_p \times f_0}$



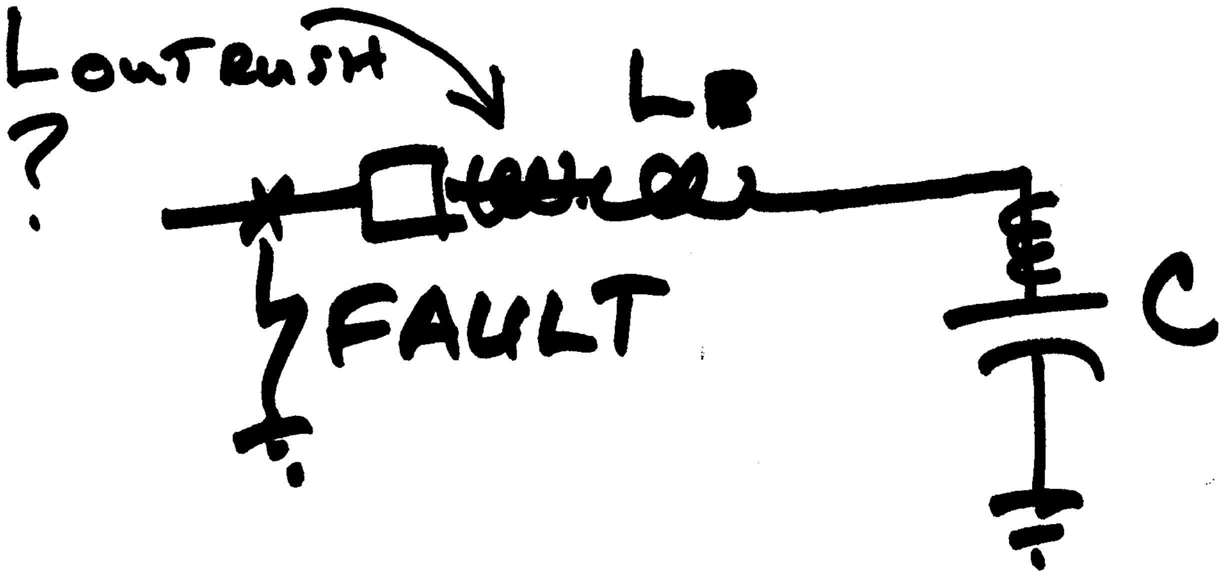
Common Approach for all RLC ckts:

- Define operative L, C
- Find ω_0, Z_0
- Find $\Delta V = V(\infty) - v(0^+)$
- Find I_p
- Sketch waveforms –
- Check w/ ATP

$$I_p \times f_0 \le \underline{2\times10^7}$$

$$I_p = \frac{V_p}{\sqrt{\frac{L}{C}}} \qquad f_0 = \frac{1}{2\pi\sqrt{LC}}$$

ADD



$$\frac{V_p}{\sqrt{\frac{L}{C}}} \times \frac{1}{2\pi\sqrt{LC}} \le 2\times10^7$$

$$\boxed{\frac{V_p}{2\pi L} \le 2\times10^7}$$

Solve for L ← <u>Min required</u>

$$L = L_{BUS} + L_{REACT}$$

If $L \le L_{BUS}$ ⟹ No Reactor Needed!

If $L > L_{BUS}$

$$\Longrightarrow L_{REACTOR} = L - L_{BUS}$$

For definite purpose:

a) $\omega_0 < \omega_{rated}$

[redacted]

b) ~~w~~ f $I_p < I_{rated}$

$$\boxed{I_p \omega_0 < \text{rated.}}$$

R's, L's & C's in EMTP

Notes

EMTP – BPA, 1970 → '85

1985 EPRI | DCG ↓

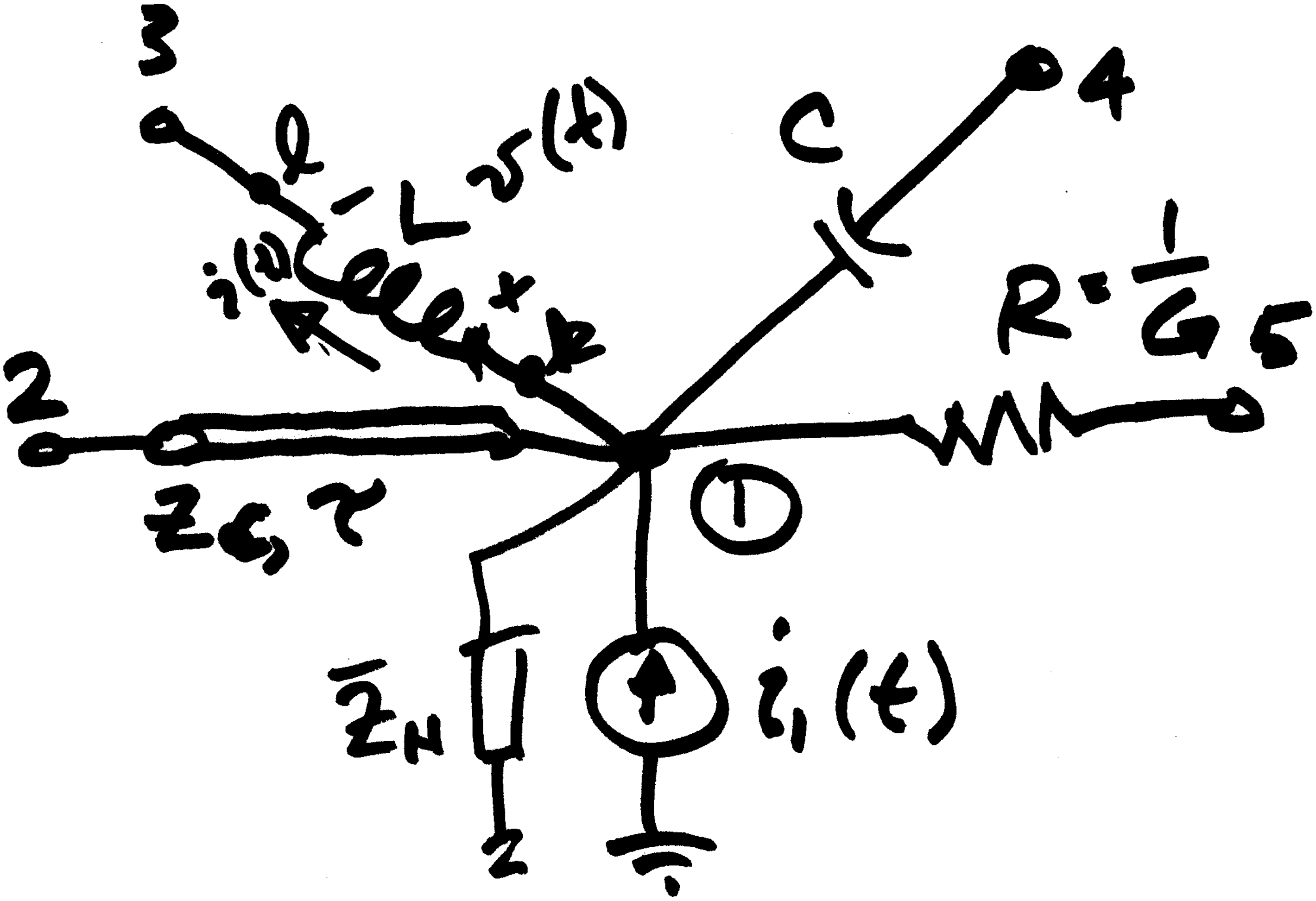
EPRI EMTP
or DCG EMTP
– TACS ↓
EMTP/RV ✓

F.O.I.
1987 ↓

ATP ✓

Different:
– TACS
– MODELS
} Controls

OTHERS:
– EMTDC/Pscad
– Micro-Tran ✓
– ABB/Siemens
– EDF – MORGAT



Side Note:

Mathematical Structure is

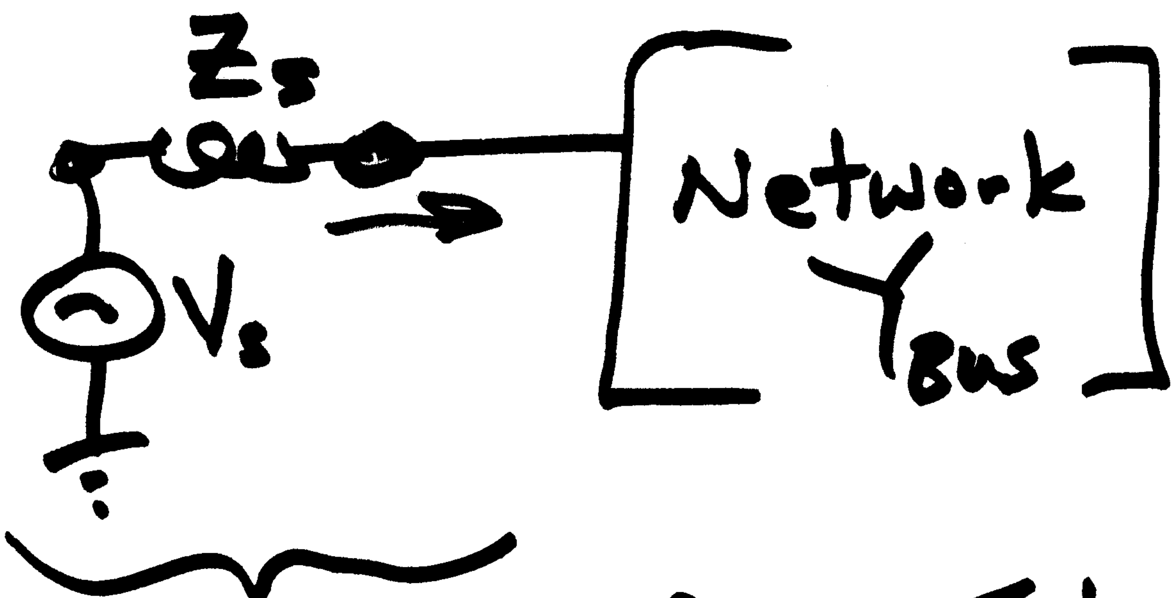
$$[Y][V] = [I]$$

sparse → $[Y]$

↑ node V's ($[V]$)

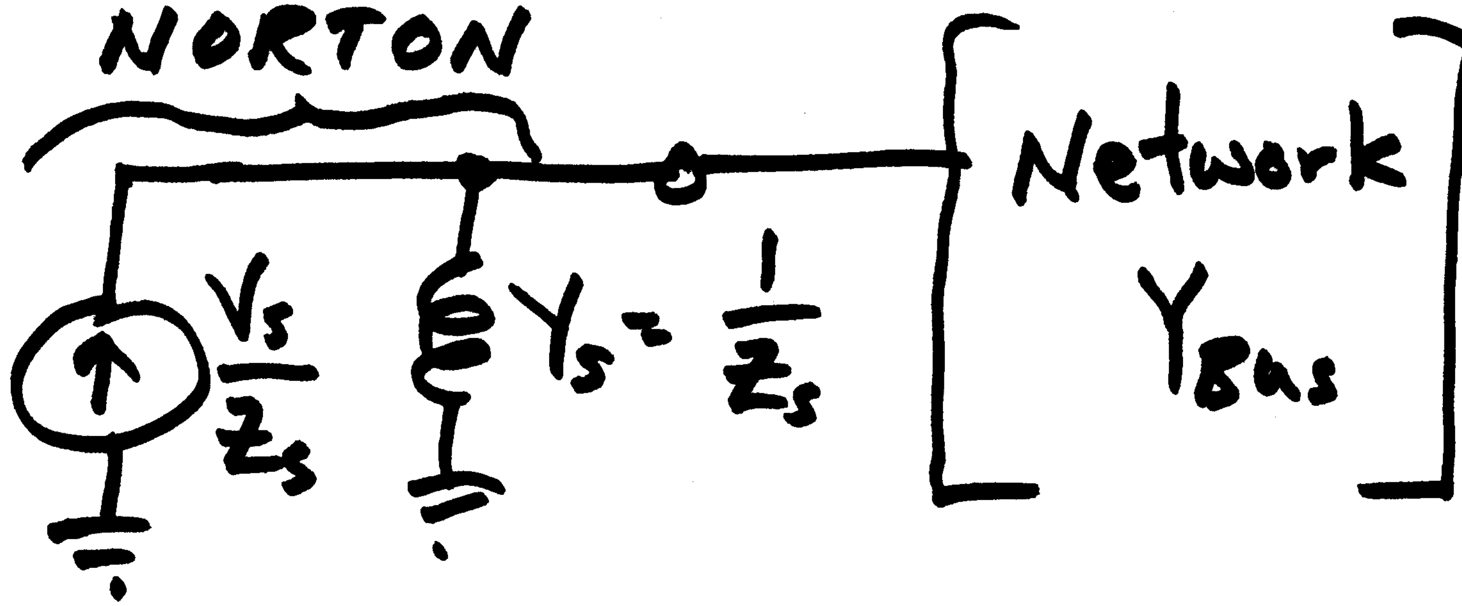
↑ injected currents ($[I]$)

Injected Currents!

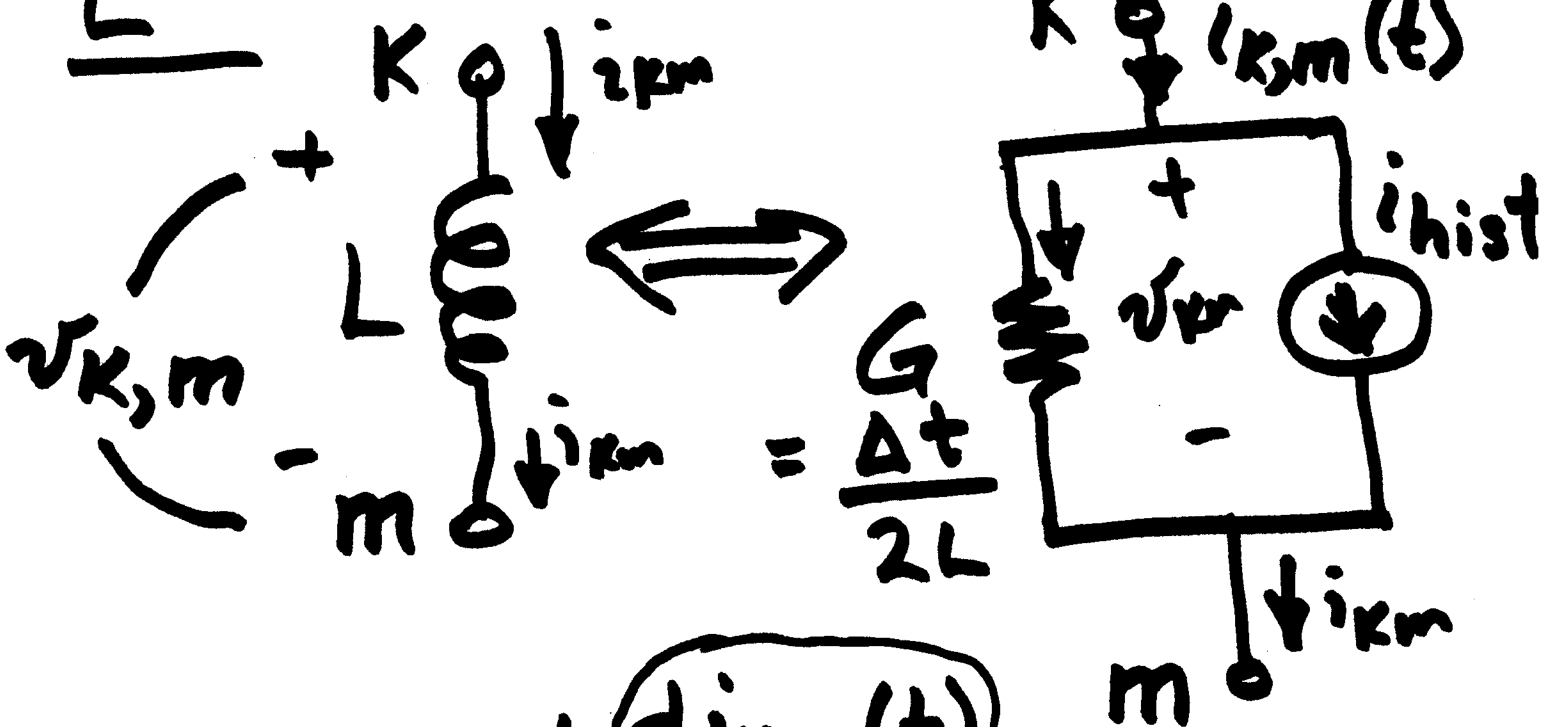


Thevenin = Bad : Extra Node
V = Fixed

Instead, convert to Norton:



L

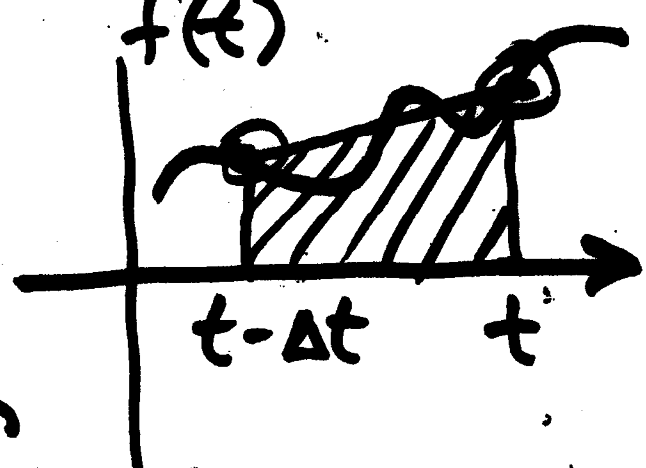


$$v_k - v_m = L \frac{d\, i_{k,m}(t)}{dt}$$

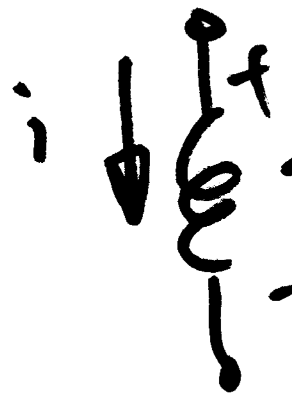
$$d\, i_{k,m}(t) \cong \underbrace{\{ i_{k,m}(t) - i_{k,m}(t-\Delta t) \}}_{\Delta i}$$

$$dt \cong \Delta t$$

Trapezoidal Integration



$$\int_{t-\Delta t}^{t} f(t)\, dt$$



$$v = L\frac{di}{dt}$$

$i = ?$

$$v\,dt = L\,di$$

$$di = \frac{1}{L}v\,dt$$

$$i = \frac{1}{L}\int_0^t v\,dt$$

Δt in EMTP cannot be as small as dt, Δt is finite.

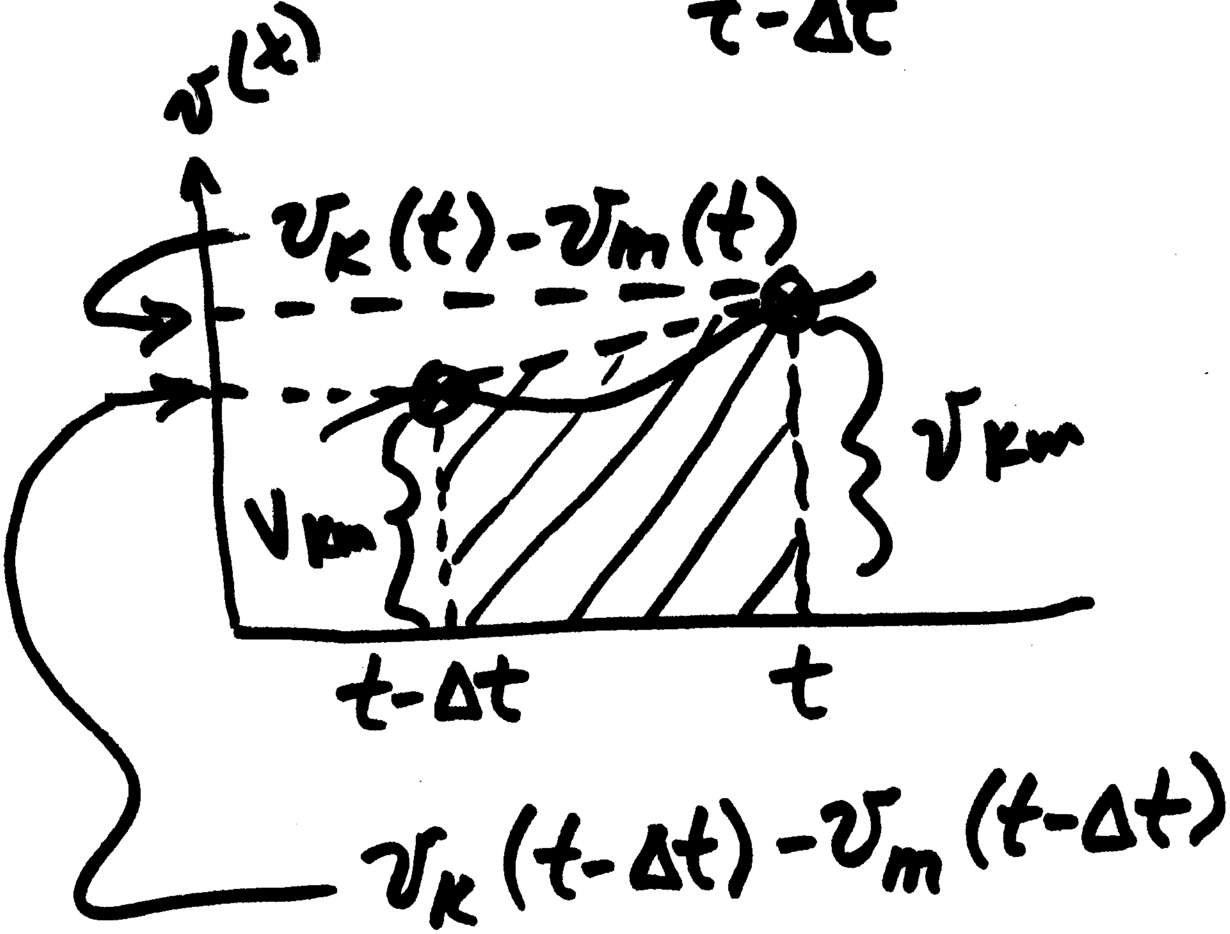
6A

Look at Trapezoidal implementation of eqn:

6B

$$v_k(t) - v_m(t) = L \frac{d\, i_{k,m}(t)}{dt}$$

$$d\, i_{k,m}(t) = \frac{1}{L} \int_{t-\Delta t}^{t} \left[v_k(t) - v_m(t) \right] dt$$



The integral can then be approximated as the area of the trapezoid:

$$\frac{1}{L}\int_{t-\Delta t}^{t}\left[v_K(t)-v_m(t)\right]dt$$

$$\cong \frac{\Delta t}{L}\left[\frac{v_K(t)-v_m(t)+v_K(t-\Delta t)-v_m(t-\Delta t)}{2}\right]$$

(i.e. area of trapezoid = $\Delta t \times$ average height of sides)

$$d i_{Km}(t) = \frac{1}{L} \int_{t-\Delta t}^{t} \left[v_K(t) - v_m(t) \right] dt$$

$$\downarrow$$

$$i_{Km}(t) - i_{Km}(t-\Delta t)$$

7A

Integral is:

$$\frac{1}{L}\left[v_k(t) - v_m(t) + v_k(t-\Delta t) - v_m(t-\Delta t)\right]\frac{\Delta t}{2}$$

---

putting pieces together,

~~check~~ OK

$$i_{k,m}(t) \cong i_{k,m}(t-\Delta t) + \frac{\Delta t}{2L}\left[v_k(t) - v_m(t) + v_k(t-\Delta t) - v_m(t-\Delta t)\right]$$

Separating (t) & $(t-\Delta t)$ terms,

$$i_{m,k}(t) \cong \underbrace{\overbrace{\frac{\Delta t}{2L}}^{G}\left[v_k(t) - v_m(t)\right]}$$

Current at time = t for present voltage drop

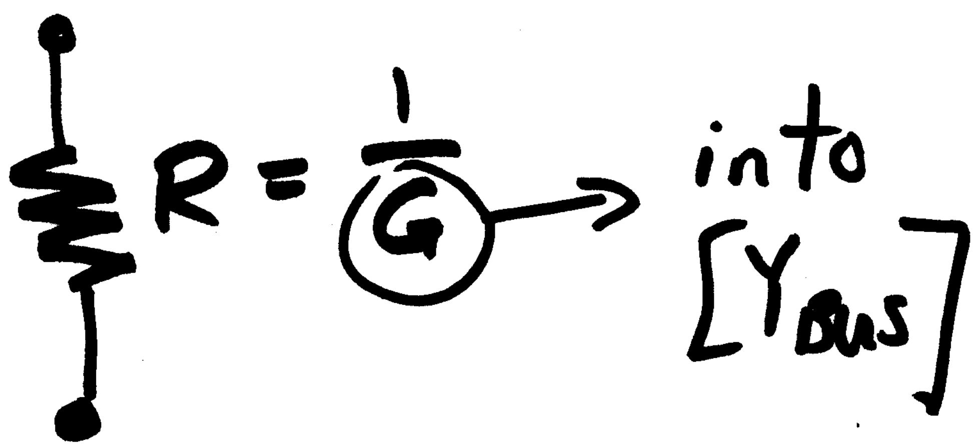
$$+ \underbrace{i_{k,m}(t-\Delta t) + \frac{\Delta t}{2L}\left[v_k(t-\Delta t) - v_m(t-\Delta t)\right]}$$

$I_{hist} = I_{k,m}$ = Summation of all currents at past time steps, i.e. $t-\Delta t$, $t-2\Delta t$, $t-3\Delta t$, ...

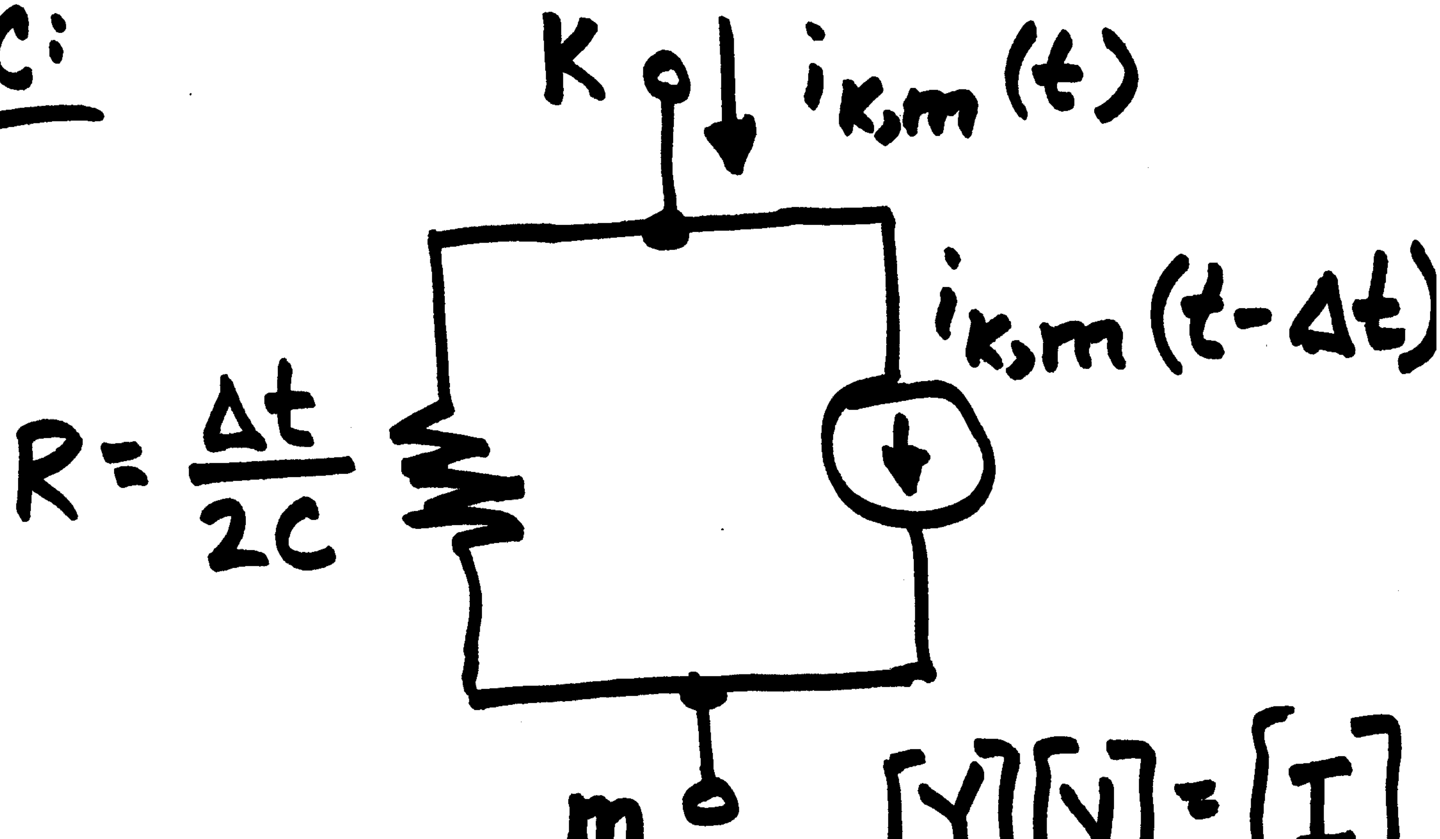
Initial iteation: $\boxed{I_{hist}(0) = i(0).}$

$[Y_{BUS}]$ is augmented according to system elements needed.

R:

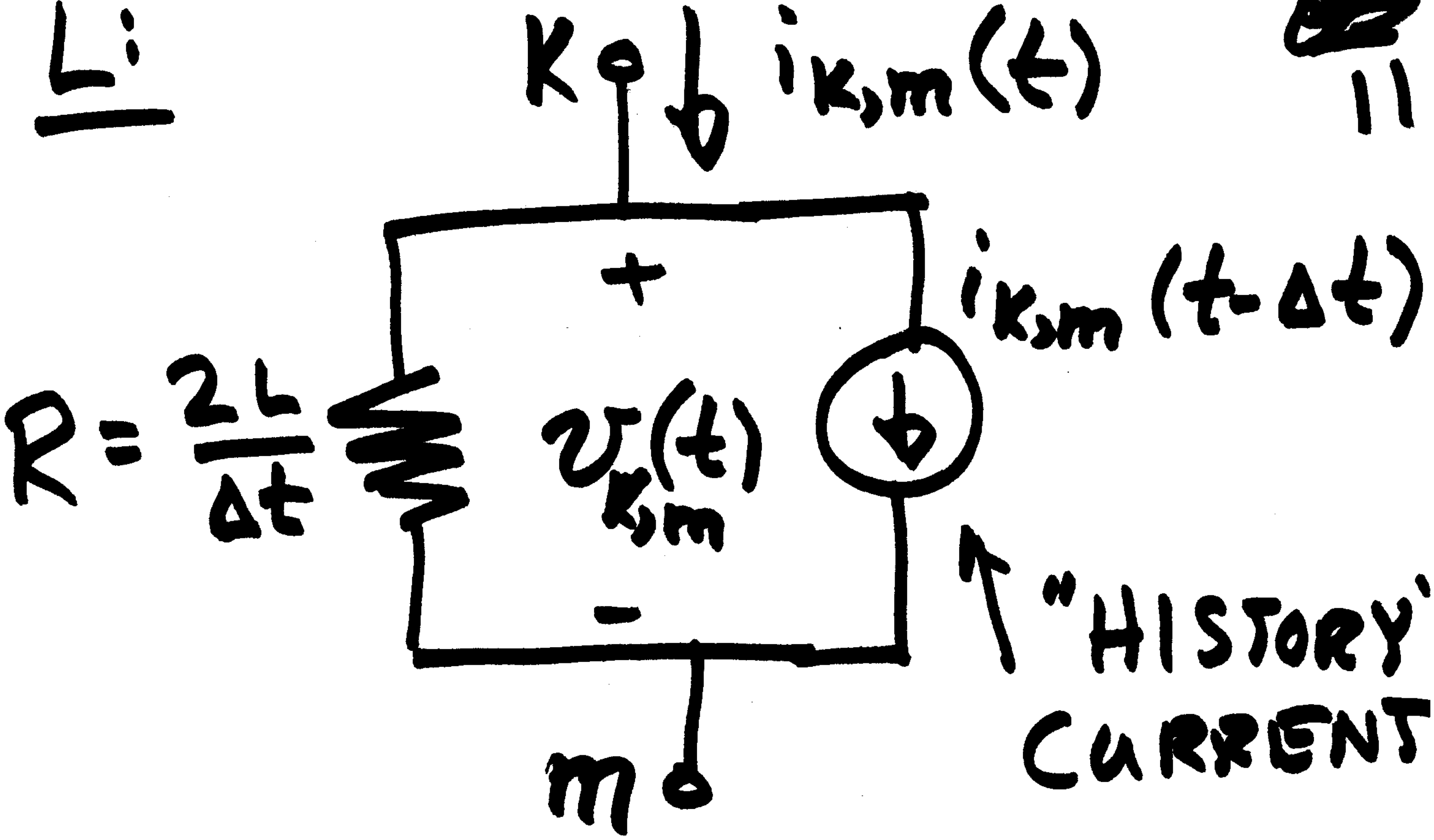


C:



$$[Y][V] = [I]$$

L:



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