EE 5220 - Lecture 10 Monday Jan 29, 2024

Topics for Today:

- Startup
  - Web page: https://pages.mtu.edu/~bamork/ee5220/
  - Book, references, syllabus, more are on web page.
  - 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 soon posted. Partnered exercise. Due Tues Feb 13th.
- ATP Simulation pointers
- Cap Bank Switching (continued)
  - Discussion - how to carry out HW#4
  - Parameters
    - Setup of this simple system simulation.
    - Cap Bank configurations
    - Transformer parameters
    - Rules of thumb for impedances

ATP Simulation Pointer of the Day:

Always ground one point on your circuit. This avoids the problem of “floating subnetwork.” Essentially this is a situation where the admittance matrix that describes the circuit is singular. If the program would attempt to proceed with LU factorization there would be a divide by zero error and the program would crash.

Note: In ATP, there is an undesirable and somewhat random automatic “correction” of this situation, where one node is grounded to fix the situation, but the user may not be aware that this has been done or which node has been grounded. Better: you control the situation by grounding the node that needs to be grounded.

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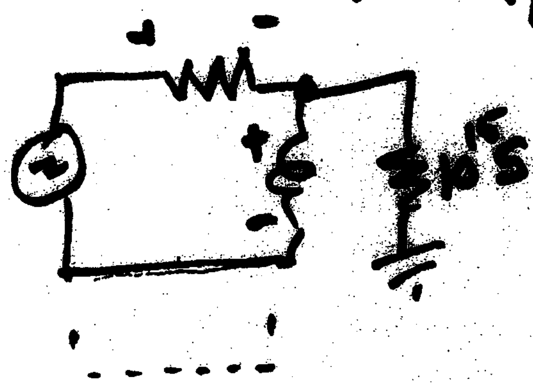
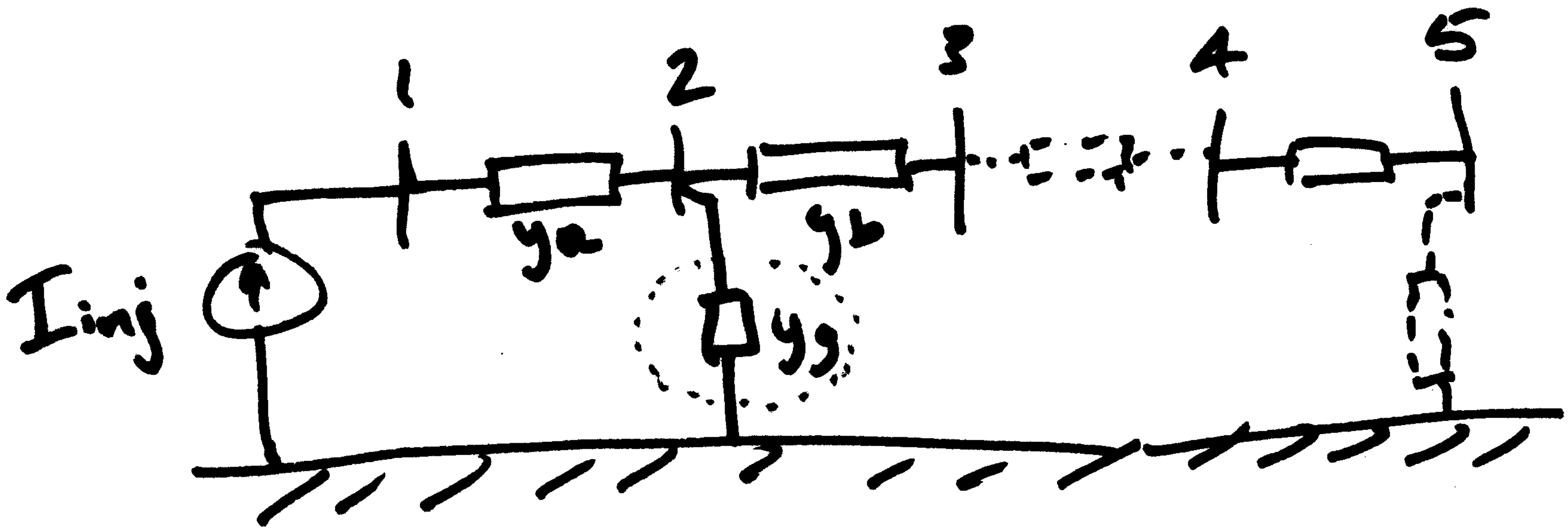
$$[Y][V] = [I]$$

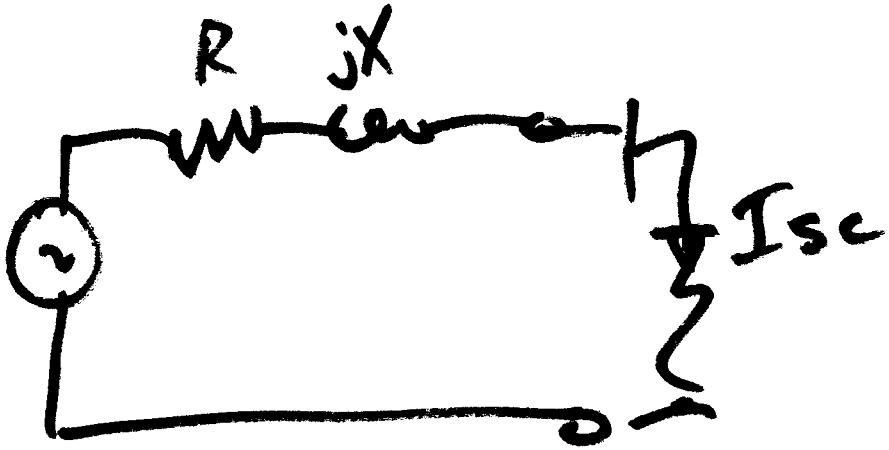
Node Voltages ↑ ($[V]$) — Injected Currents ↑ ($[I]$)





$$\begin{bmatrix} y_a & -y_a & 0 \\ -y_a & y_a+y_b+y_g & -y_b \\ 0 & -y_b & y_b \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \\ V_3 \end{bmatrix} = \begin{bmatrix} I_{inj} \\ 0 \\ 0 \end{bmatrix}$$

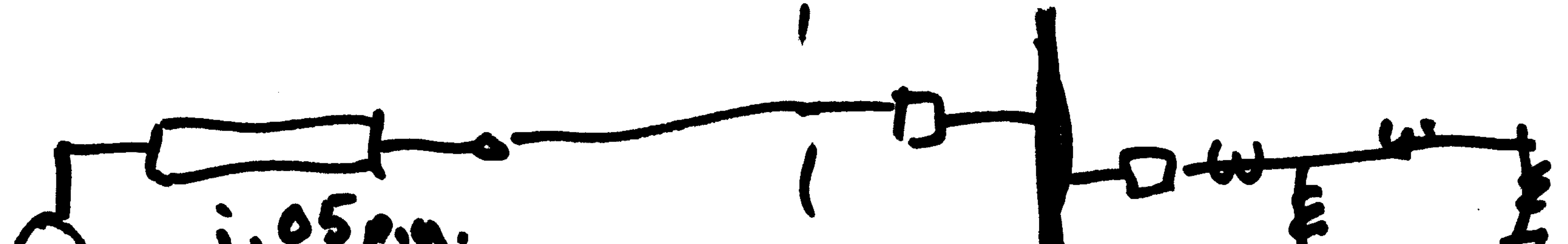
$0 \approx 10^{-15}$ or 10^{-12} $\quad \infty \approx 10^{12}$ or 10^{15}



$$\frac{X}{R} = 7$$

$$MVA_{sc} = \underline{\qquad\qquad} = \sqrt{3}\, V_{LL}\, I_{sc}$$

$$Z_{TH} = \frac{V_{LN}}{I_{sc}}$$



$j.05\ p.u.$

$= j6.6\ \Omega$

$= \underline{\underline{17.5\ mH}}$

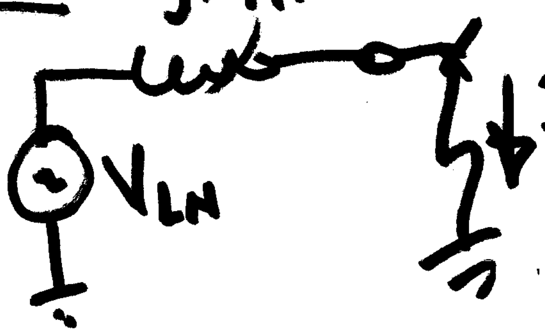
115-KV
100 MVA

$$Z_B = \frac{115^2}{100} = \underline{132.2\ \Omega}$$

$$f_0 = \frac{1}{2\pi\sqrt{LC}}$$

$$Z_0 = \sqrt{\frac{L}{C}}$$

"**S.C. MVA**"



$$\text{S.C. MVA} = \sqrt{3}\, V_{LL}\, I_{sc}$$

Basic Series Impedances (Ohm/mi):

	Xo/Ro	Ro	Xo	R1	X1	X1/R1	L1 (uH/ft)
4/0 Cu	4.721323	0.5867	2.77	0.303	0.8008	2.64	0.402
556.5 Al	5.76318	0.4704	2.711	0.1871	0.7421	3.97	0.373
1590 Al	7.415919	0.3568	2.646	0.07313	0.677	9.26	0.340
5" Al	8.11904	0.3041	2.469	0.0209	0.5005	23.95	0.251

Note: Greenwood says 0.2 - 0.4 uH/f is typical. 0.4 for smal conductor and 0.2 for large-size bus tubing.

Note: Zo values seem to be typically 3x bigger than Z1. This compares to T-Line sections that have no shield/ground wire.

$\rho = 1\,\Omega\text{-m}$

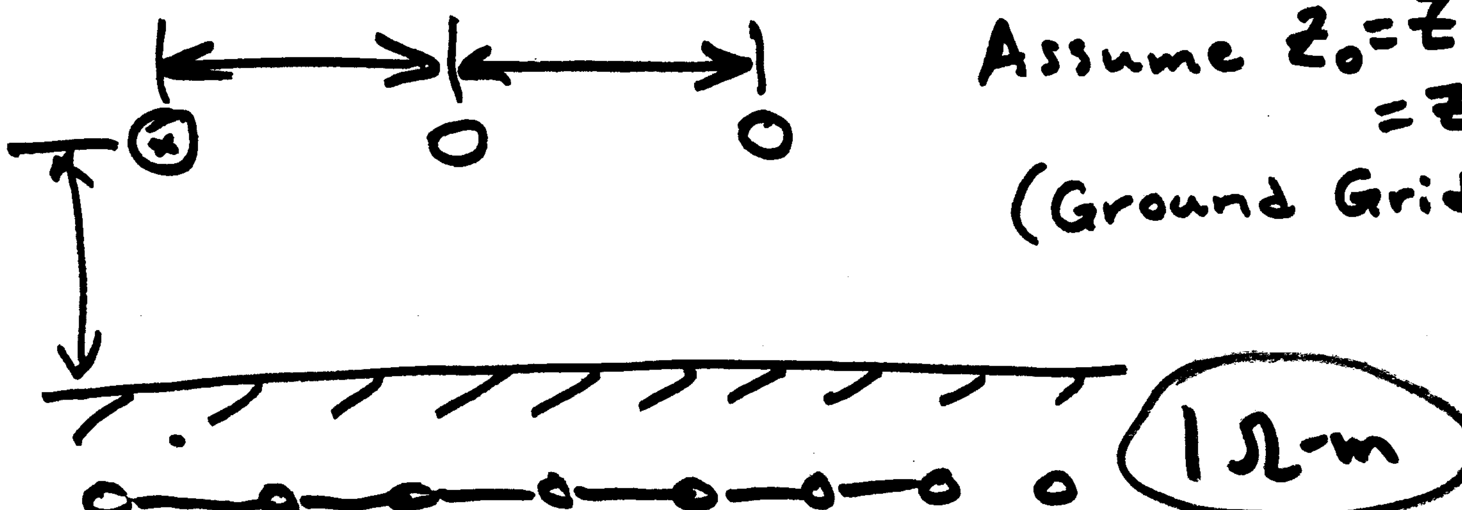
Damping: $E = \frac{1}{2}CV^2$

Strain Bus - Overhead Conductor for bus conductor.

Tube/Pipe Bus - Al tube or channel

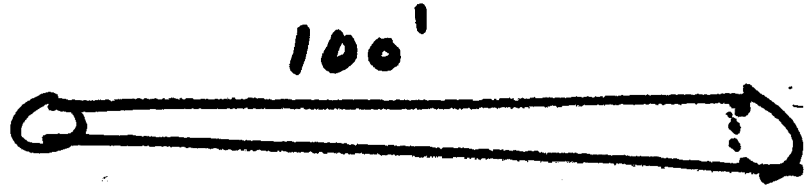
Focus on X/R ratio and L/ft.

Assume $Z_0 = Z_1 = Z_2$ (Ground Grid!)



- Some parameters - vital
- " " - not important
- Some effects can be ignored.

Ex:



$L = (.25)(100') = \underline{25\,\mu H}$

$X_L = 2\pi f L\ \Omega$

$= 377 L\ \Omega = \underline{9.4\ m\Omega}$ @60Hz

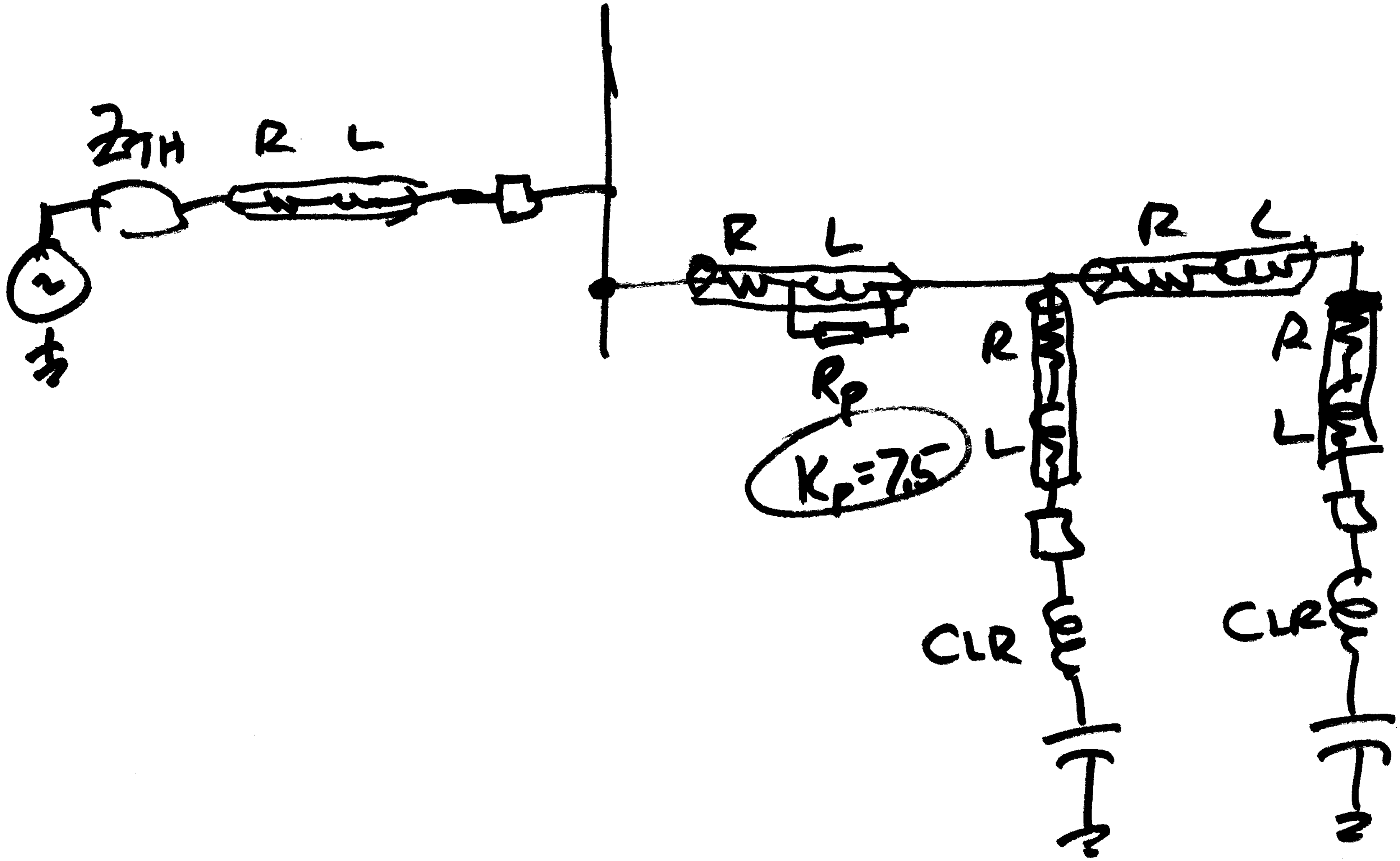
$= \underline{78.5\,m\Omega}$ 500 HZ

$=$ 785 [redacted] Ω 5KHZ

Typical Spacings and Clearances in a Substation

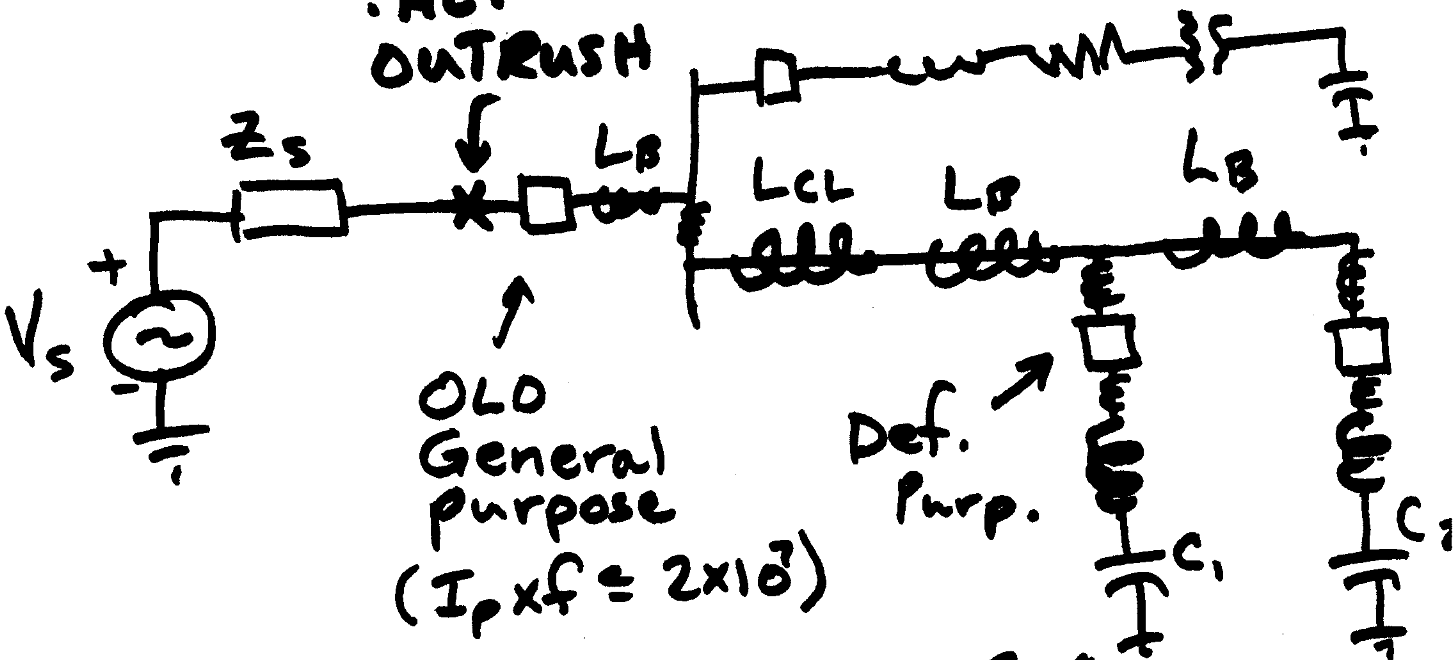
See up-to-date NESC to verify !

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											

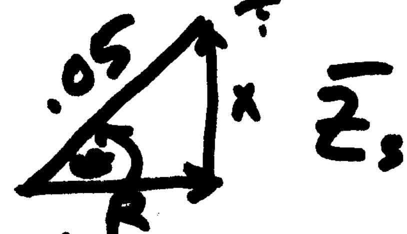


27H
R
L
R
L
R
L
Rp
Kp=7.5
R
L
R
L
CLR
CLR

See SK. ~~ADP~~ .ACP – <u>Per Phase</u>

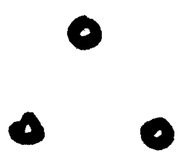


$$V_s = \frac{\sqrt{2} \times V_{LL,RMS}}{\sqrt{3}} = V_p$$



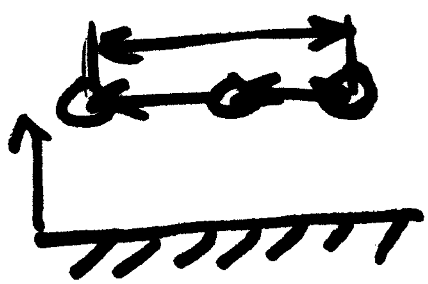
Z_s = From S.C. Study (CAPE, PSS/E)
or assume 5%, X/R = ? USE Judgement

Bus Sections – Go to Sr. <u>Power Book</u>



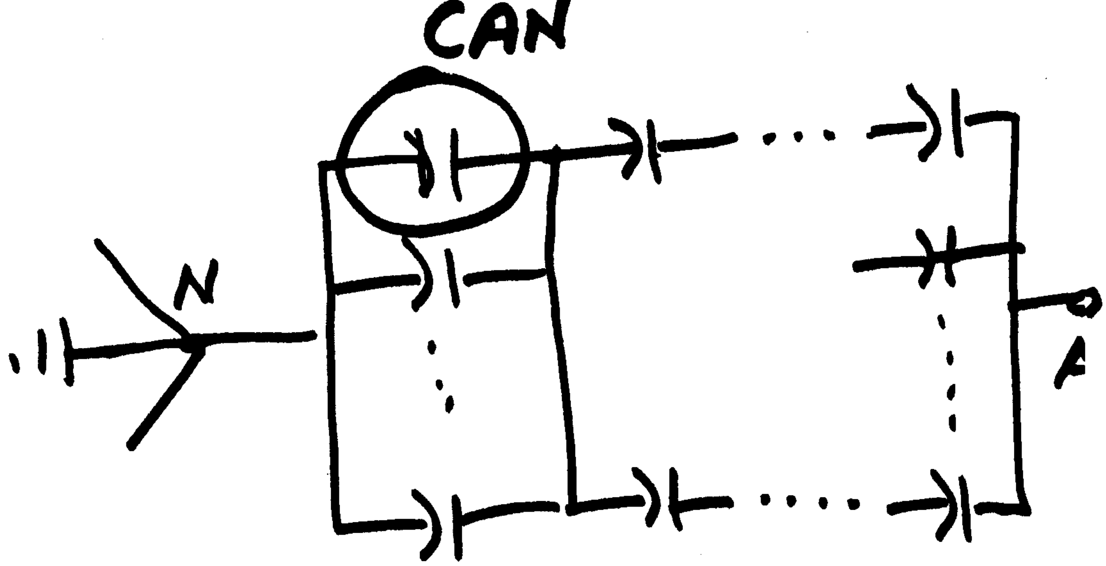
$$\boxed{L = K \log \frac{D}{r'}} \quad \frac{\mu H}{ft}$$

R = From Tables: Ω/ft.
R_{AC} @ 50°C



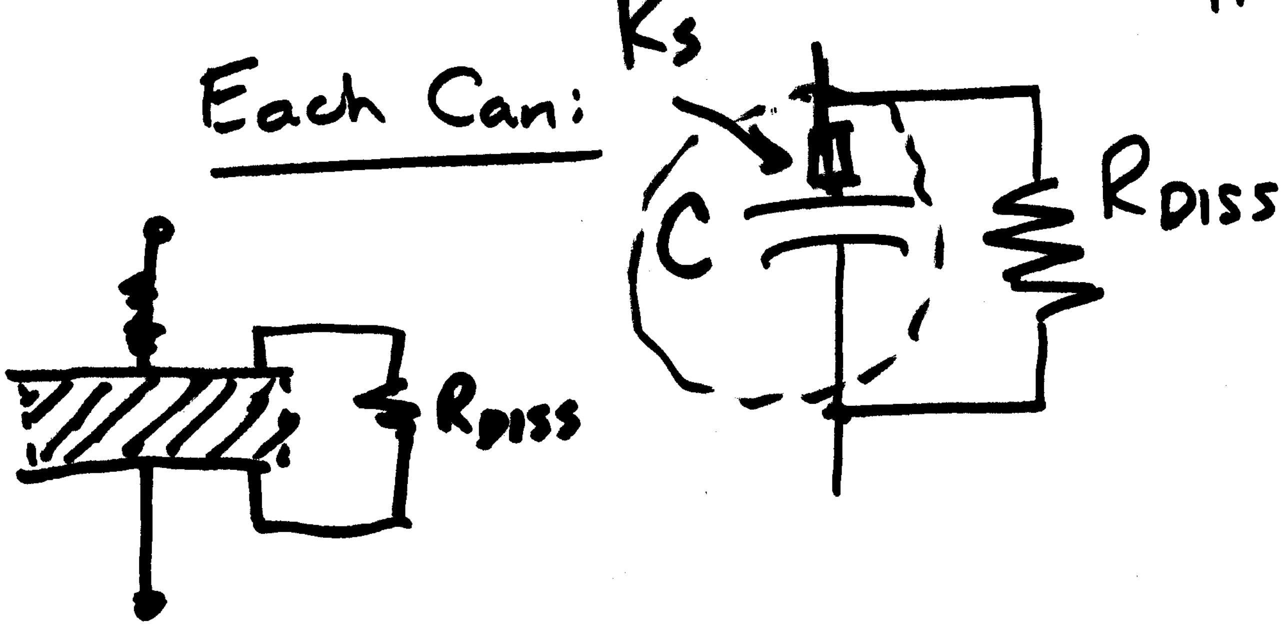
Cap Bank Values

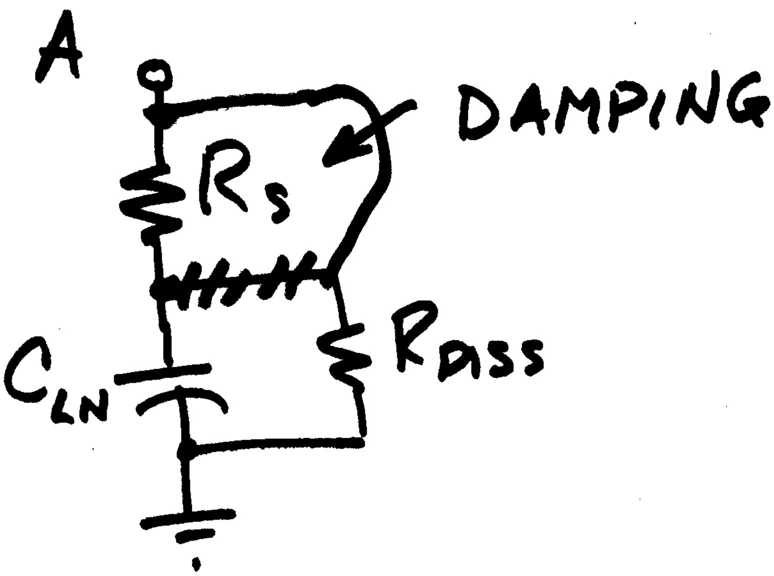
Equiv L-N Cap of a ___ MVAR Bank?



Typical Ratings: 100, 200, 400 KVAR
Low KV → 24 KV
Losses: 0.05 – 0.3 W/KVAR

Each Can:

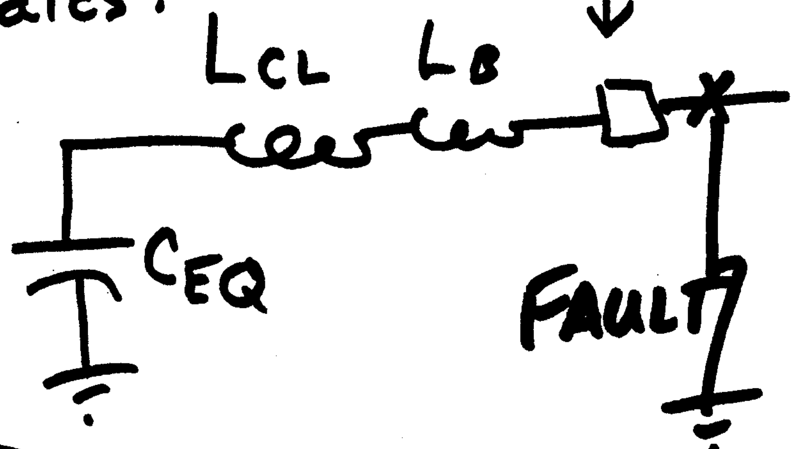




CB's - Switches

$I_p * f_0 < 2E7$

Spreadsheet Calcs:



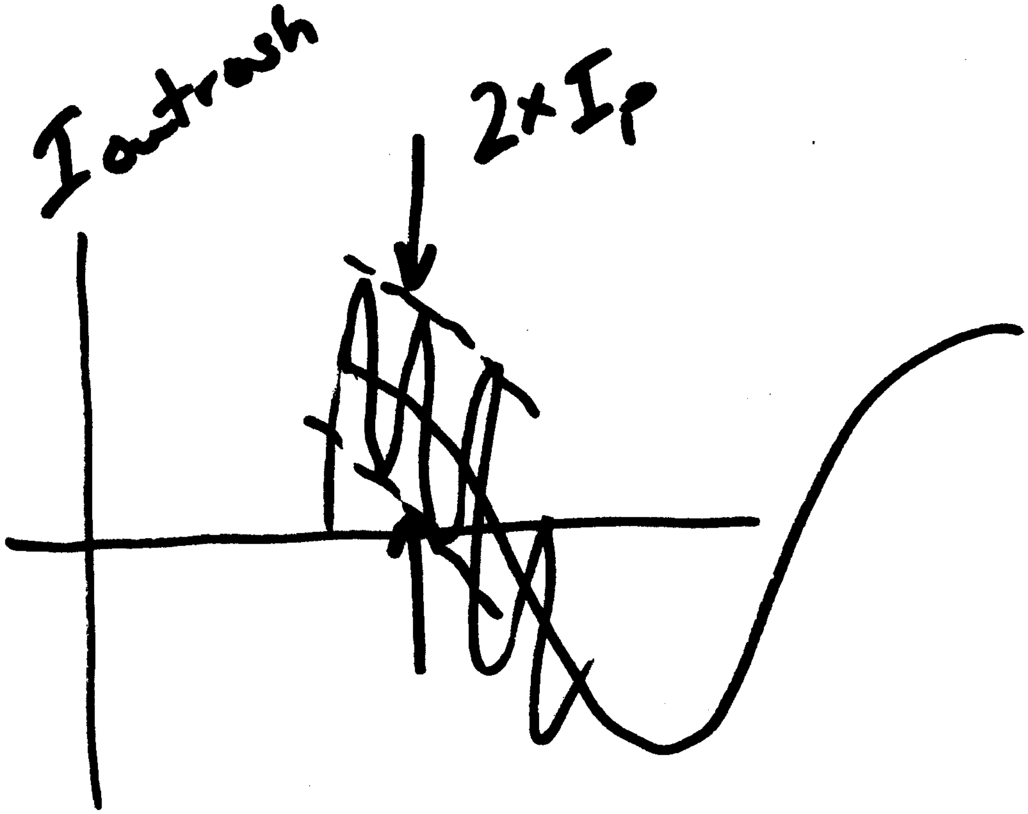
Outrush:

STEP #2

$$I_p f_0 = 2\times10^7$$

$$I_p = \frac{\Delta V}{Z_0} = \frac{V_p}{\sqrt{\frac{L_B+L_{CL}}{C_{EQ}}}}$$

$$\omega_0 = \frac{1}{\sqrt{(L_B+L_{CL})\times C_{EQ}}}$$



I outrush
2x Ip