

Topics for Today:

- Announcements
 - **Week 9: submit expanded outline of project and complete reference list**
 - Software: ATP/ATPDraw license, verify licensing when you receive it by e-mail, and we will mail you the install CD.
 - Office hrs: EERC 123 WF 4-6pm.
 - Recommended problems & all solutions: Ch.7 solns posted.
- Chapter 6 - Recap, a few last items...
 - Case Study of Series Compensation - 500-kV Forbes Line
 - Propagation Constant $\gamma = \alpha + j\beta$
 - Reflection Coefficients, Use of bounce diagrams
 - ATP Tutorial video; ATP travel wave simulation video

Chapter 7 - Network Equations, Admittance Approaches

- [Y] for Transformer Representation, 2-winding, 3-winding
- [Y] for lines and loads
- How's your linear algebra? Time to make use of it...
- Basic strategy for building up [Y] for whole network

$$[Y_{Bus}] [V] = [I_{inj}]$$

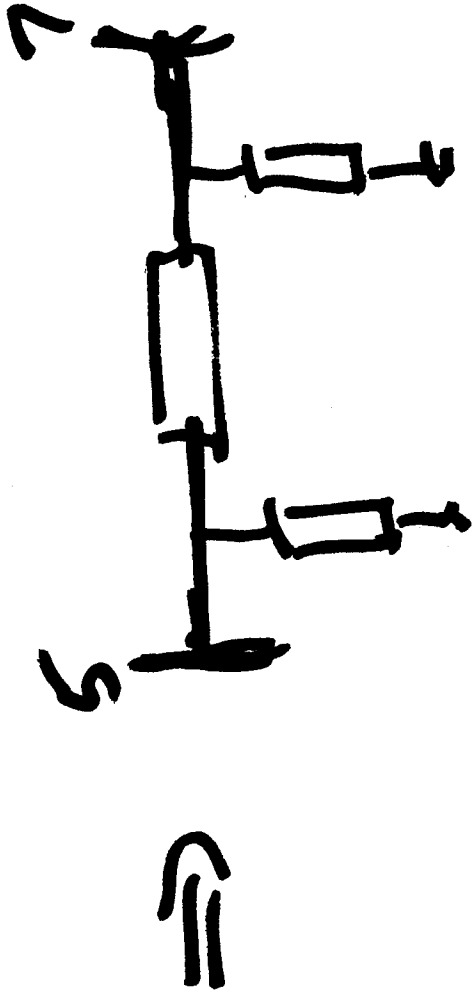
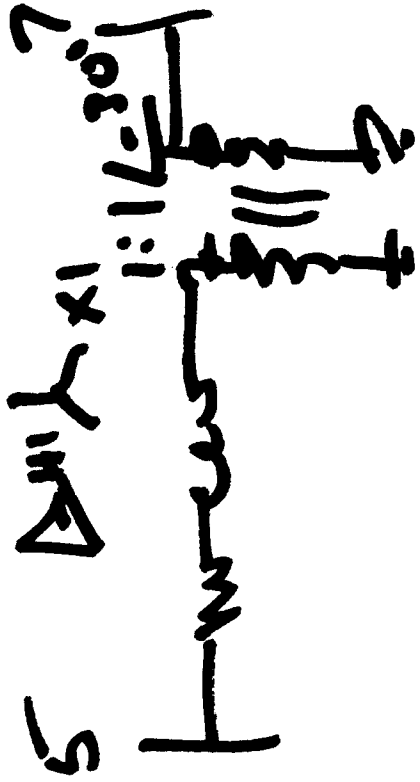
$$[Z][I] = [V]$$

unknown

construct from network params

- Lines, Cables } π
- XFMRs
- Shunt Cps, Reactors
- Synch Mach





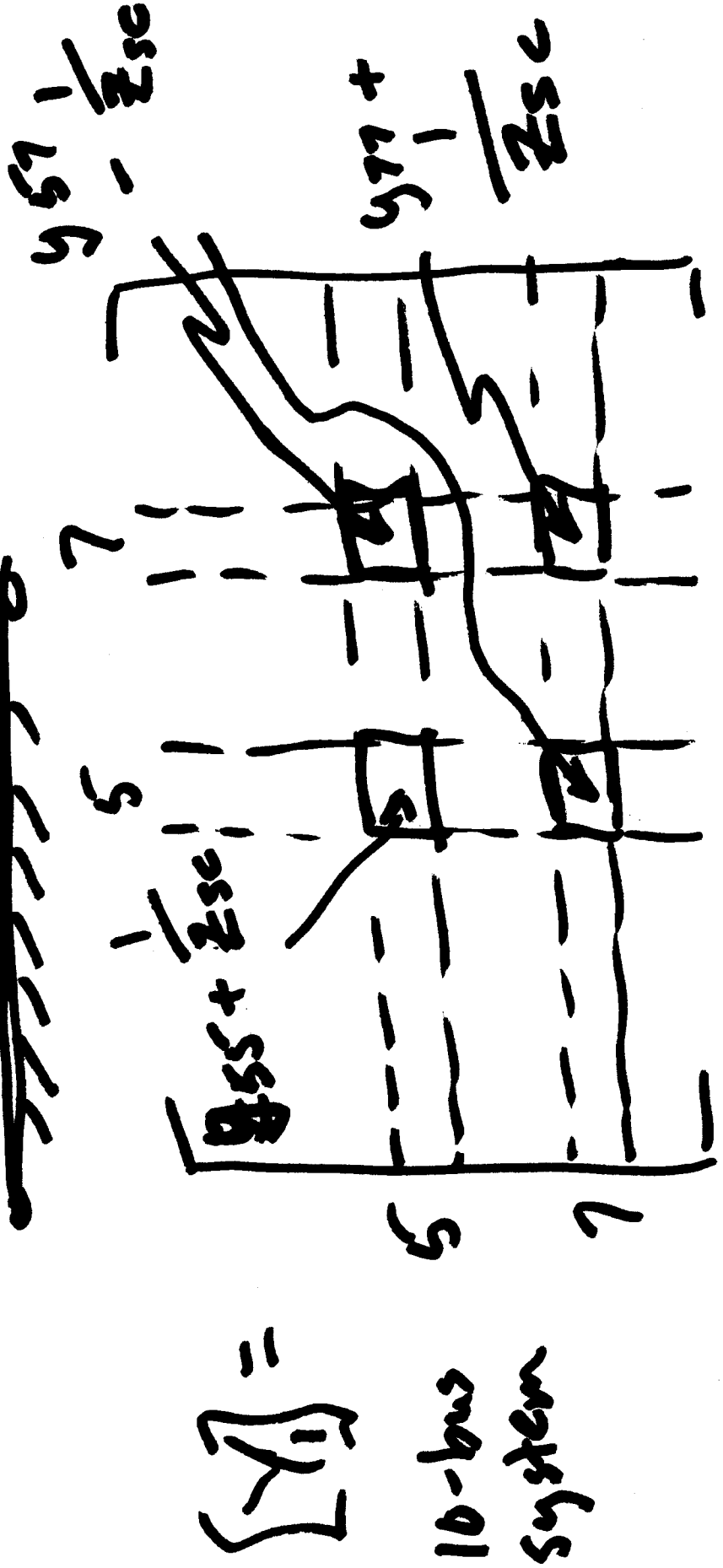
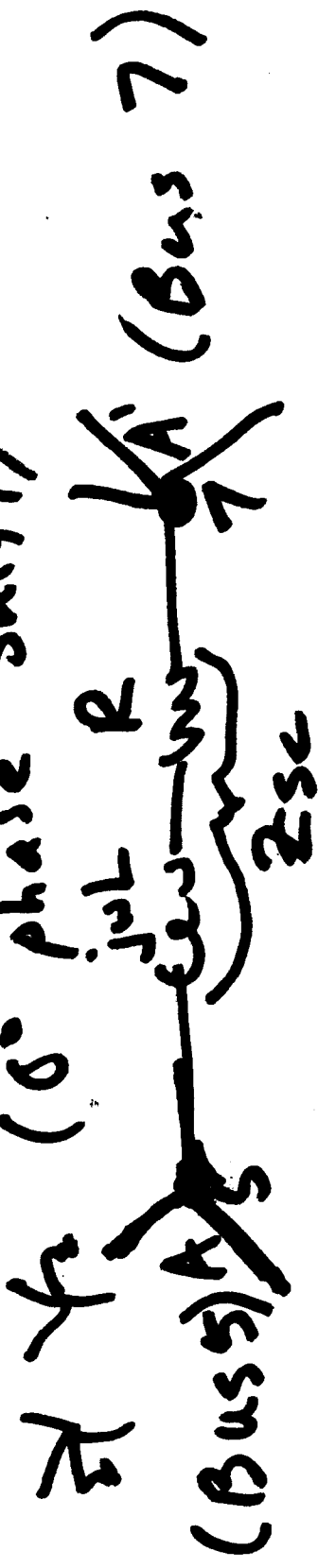
....still Only need modify

y55 y56 y57

y75 y77

2-winding Xform

(0° phase shift)



$[Y] = [Y]$

10-bus system

$[Z_{bus}]$ vs. $[Y_{bus}]$? Which is better? -1

Z is better:

- $Z_{min} = Z_{TH}$

- Good for Fault Studies, hand calcs.

$$[Z_{bus}] = [Y_{bus}]^{-1}$$

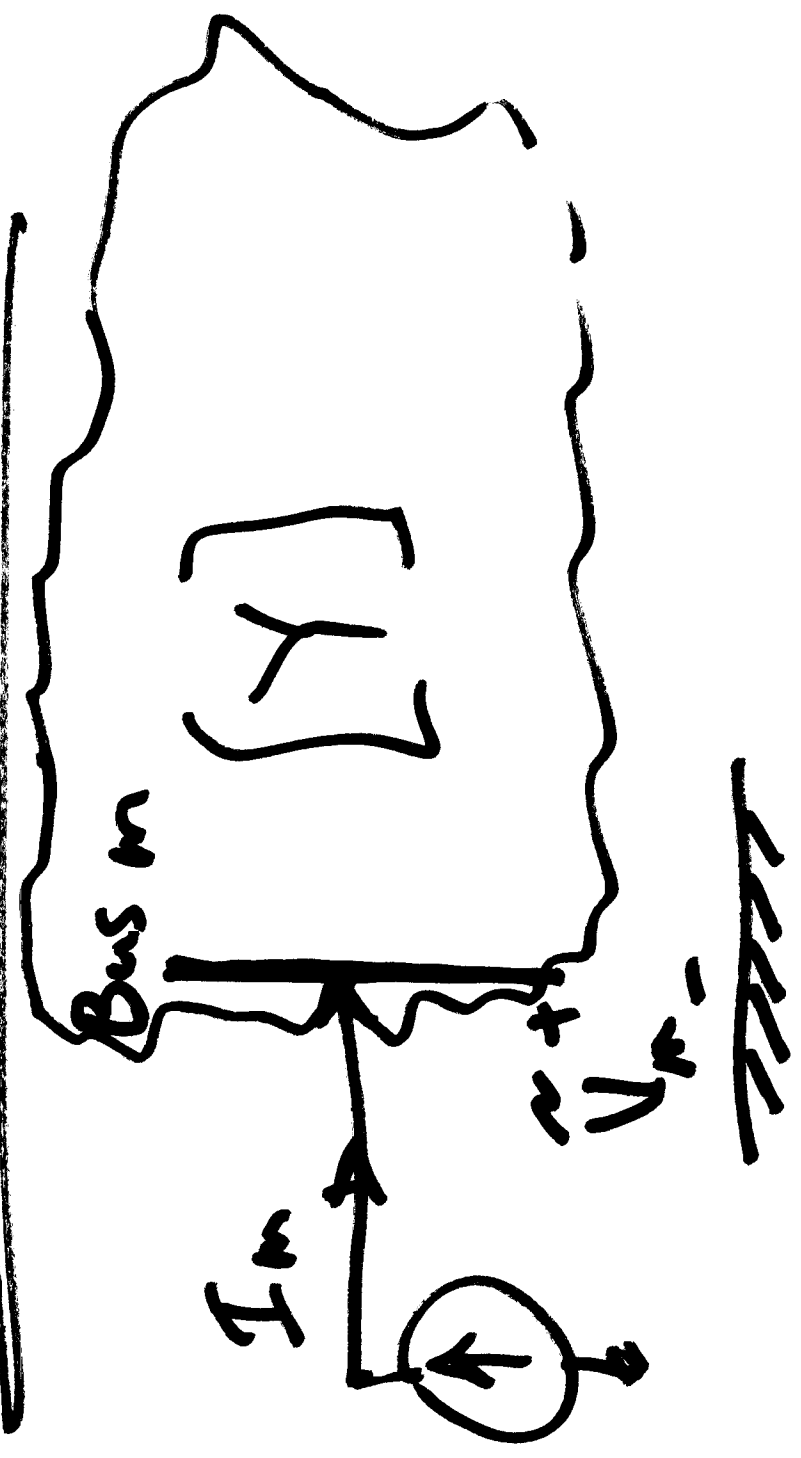
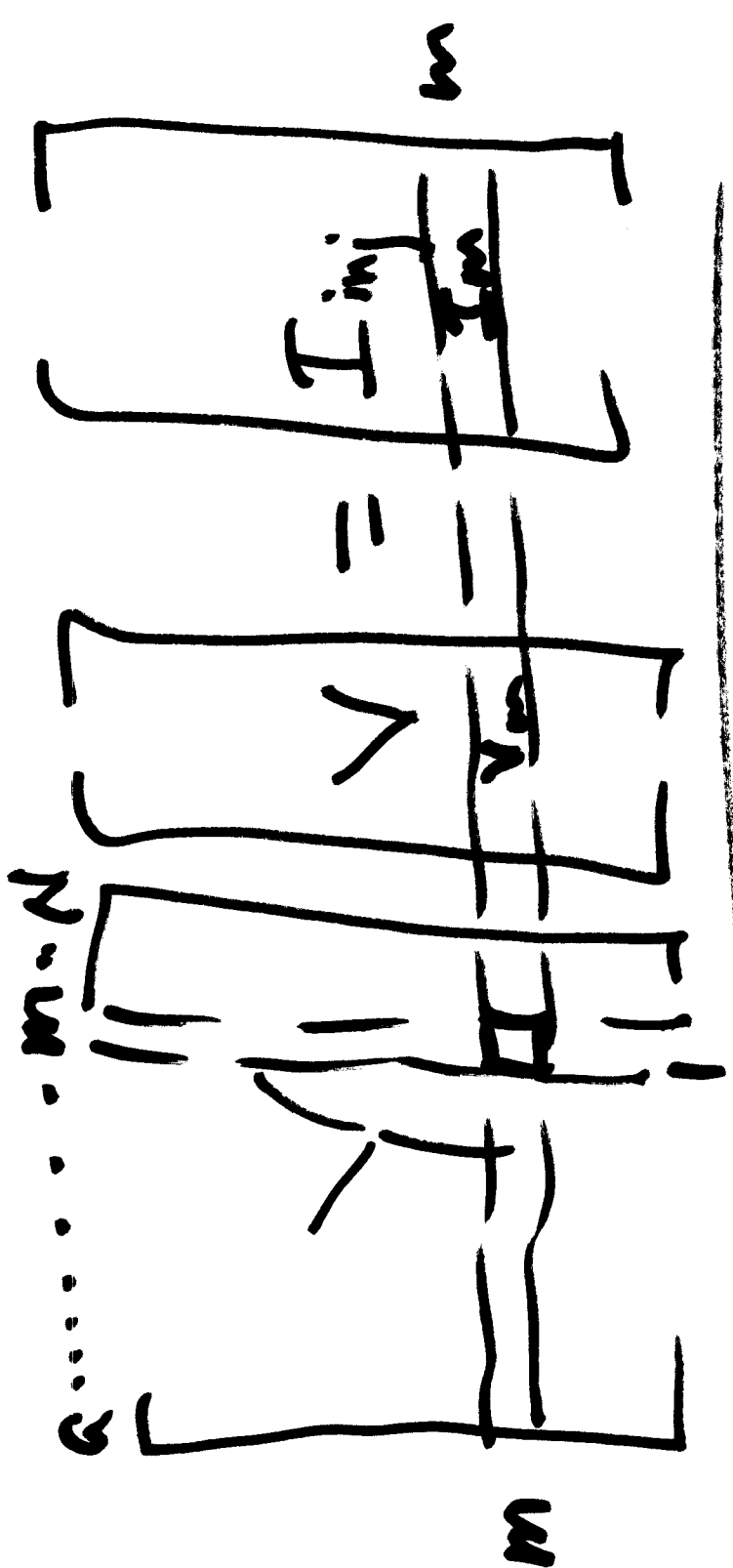
10,000 x 10,000

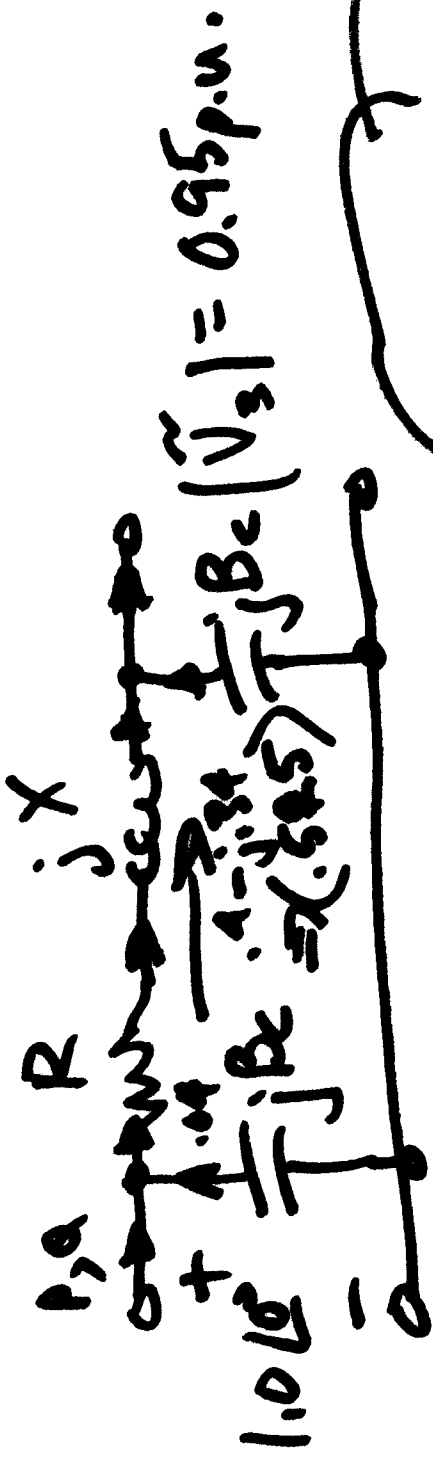
Y is better

100,000,000
800 MB

- Sparse, large systems, easy storage.

- Large systems, better throughput...





Full-Line vs. Half-Line?

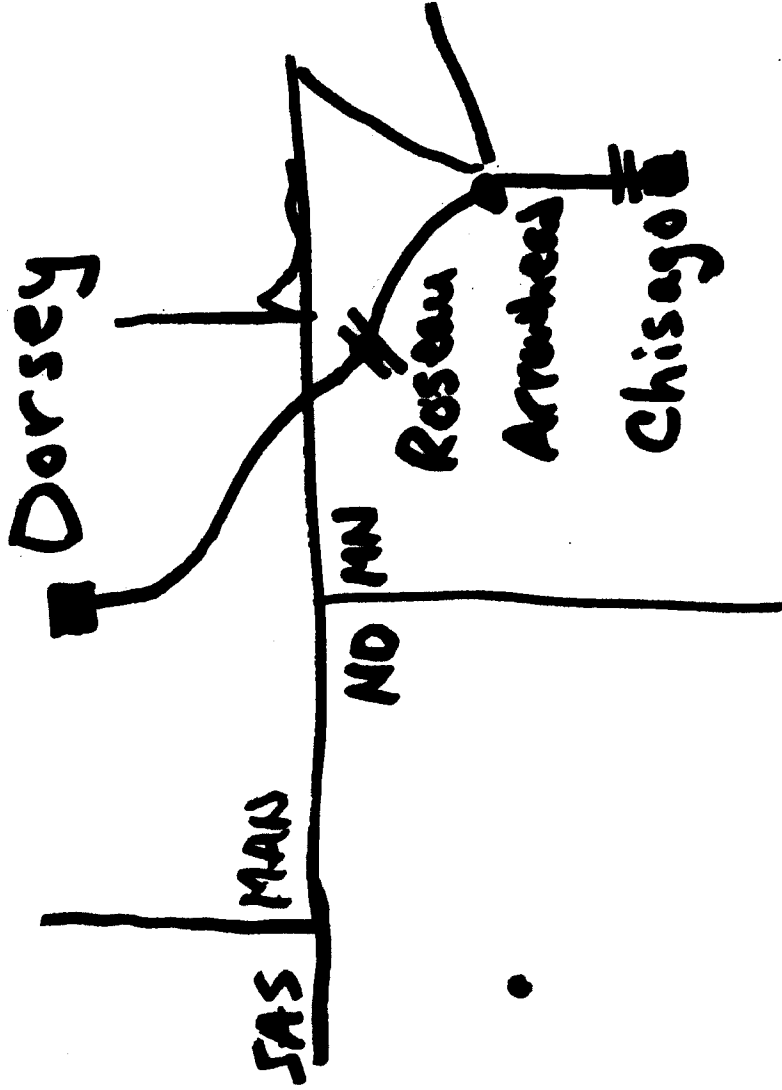
$$R = 0.08 \text{ pu}, X = 1.05 \text{ pu}, B_c = ?$$

... 8 MVAR total line charging @ rated voltage. 1.0 pu.

$$Q = \frac{V^2}{X_c} = V^2 B_c = 0.04 \text{ pu}$$

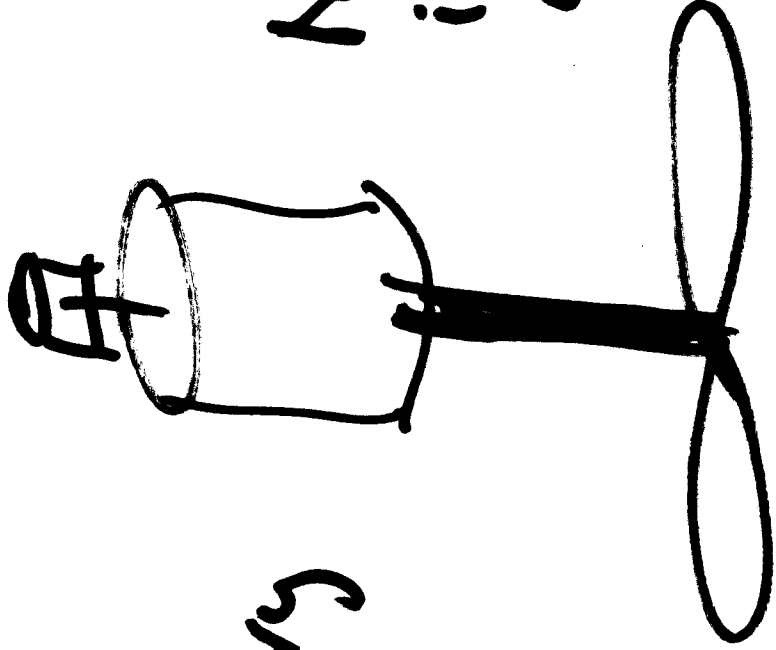
$$\Rightarrow B_c = 0.04 \text{ pu}$$

500-kV Line - May be fun to model... |

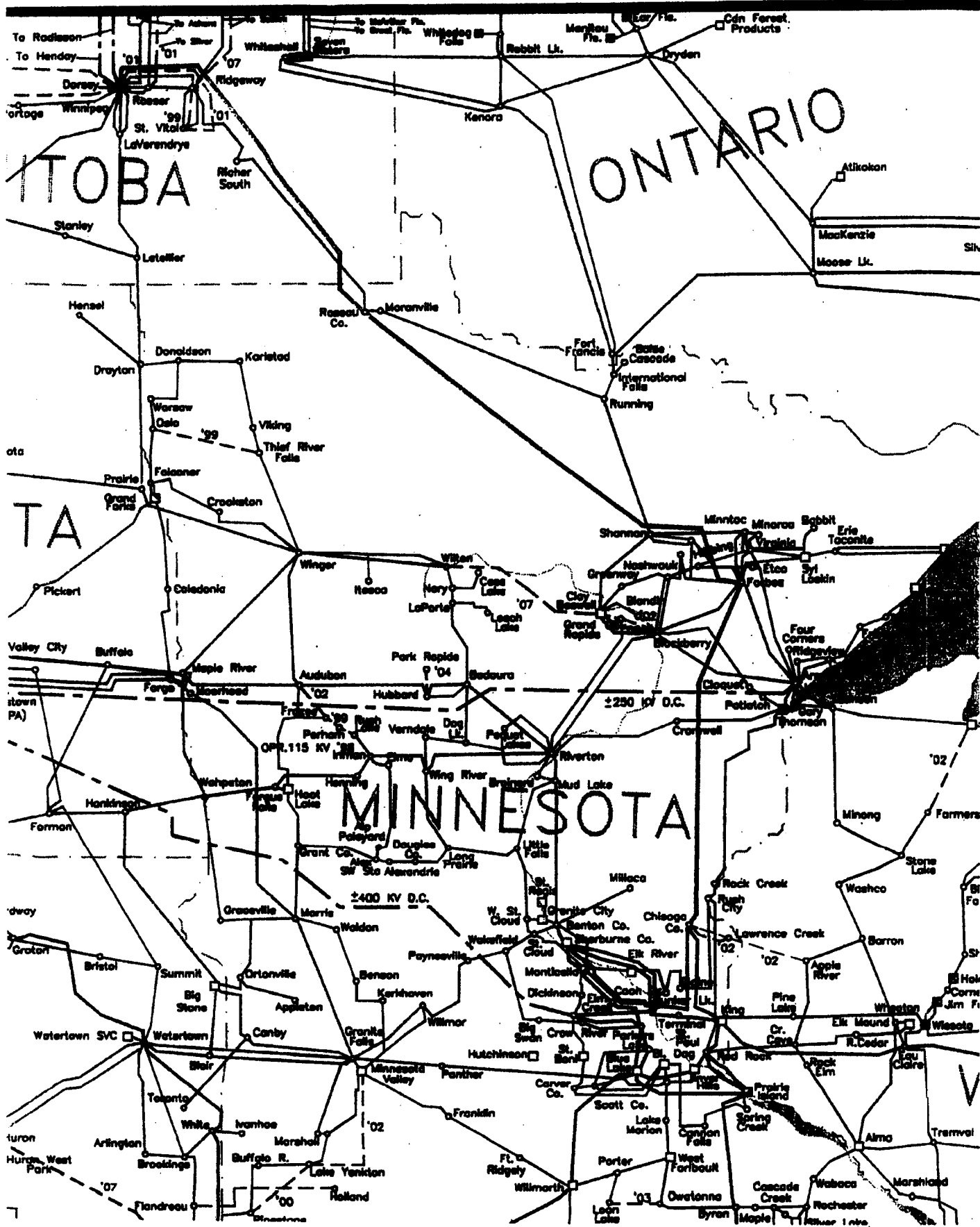


Hydro

SSR is very unlikely.



Net'l frog.
is usually
out of SSR
range.



From: "Tom Ernst (MP)" <TERNST@mnpower.com>
To: "MTU EE5200 Class Dist List (E-mail)" <EE5200-L@mtu.edu>
Subject: 500 kV Transmission Line Series Compensation
Date: Wed, 8 Oct 2003 11:18:06 -0500
X-Mailer: Internet Mail Service (5.5.2653.19)
Sender: owner-ee5200-l@mtu.edu
Reply-To: "Tom Ernst (MP)" <TERNST@mnpower.com>
X-Spam-Status: No, hits=-5.8 required=5.0
tests=BAYES_10
version=2.53
X-Spam-Level:
X-Spam-Checker-Version: SpamAssassin 2.53 (1.174.2.15-2003-03-30-exp)

Good Morning,

The 500 kV transmission line that goes from Duluth (Forbes Substation) to Winnipeg (Dorsey Substation) is series compensated for about 25% of the XI. The series capacitors are located near the line's mid-point at Rosoe, MN. We also have shunt reactors on the Duluth end to help control the Ferranti rise.

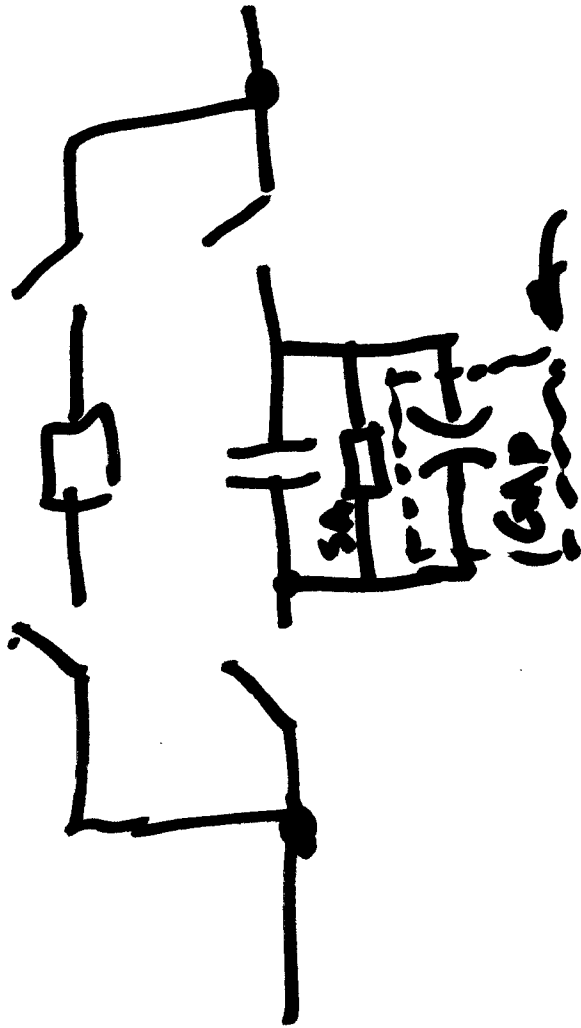
The next 500 kV line to the south from Duluth (Forbes substation) to Minneapolis (Chisago County substation) is series compensated at the Chisago Co end. I'm not sure how much compensation that is, but it is probably in the same range. The also have shunt reactors at Chisago County.

Both of these series capacitors were added as part of a project that nearly doubled the line's transfer capacity. In this case, the transfer capacity is not limited solely by the line impedance, but by the steady state export limit from Manitoba to the US which is based on over-all transfer capability of the 500 kV system plus the 230 kV tie lines that operate in parallel with the 500 kV.

One of the biggest issues with series compensated lines is the voltage rise across the capacitors during short circuits and the associated high fault currents that are created by the low X series impedance. To help with this, the series caps have flash-over gaps or non-linear resistors (varistors) across them to quickly remove (short) them during faults. This produces an interesting short circuit analysis problem since the solution is time variant as the varistor or gap conducts. Programs like ASPEN OneLiner develop steady state short circuit calculations and are not suited for time variant solutions (you have to pick which machine characteristic to use - transient or sub transient). To solve the series cap problem, ASPEN does an iterative solution where it solves the case with zero conduction in the gap and then uses the voltage rise across the cap to calculate a gap conduction. It then recalculates a new short circuit value based on that gap conduction and then repeats the process until it sees minimal change in the solution.

Tom

Series Cap



Close look at $\gamma = \alpha + j\beta$

3

$$\gamma = \sqrt{Zy} = \sqrt{(0.2 + j0.6) \text{ } \Omega/\text{mi} * j7.3 \text{ } \mu\text{S}/\text{mi}}$$

Very high ωR

\Rightarrow may assume lossless?

$$= 0.0034 / \text{mi} + j0.00212 \text{ rad}/\text{mi}$$

$$= 0.0034 \frac{\text{neper}}{\text{mi}} + j0.00212 \text{ rad}/\text{mi}$$

Tells us how much attenuation/mi the wave will experience.

$$\text{For } 250 \text{ mi: Atten} = (0.0034 \frac{\text{neper}}{\text{mi}})(250 \text{ mi}) = 0.85 \text{ or } 8.5\%$$

Reflections

2

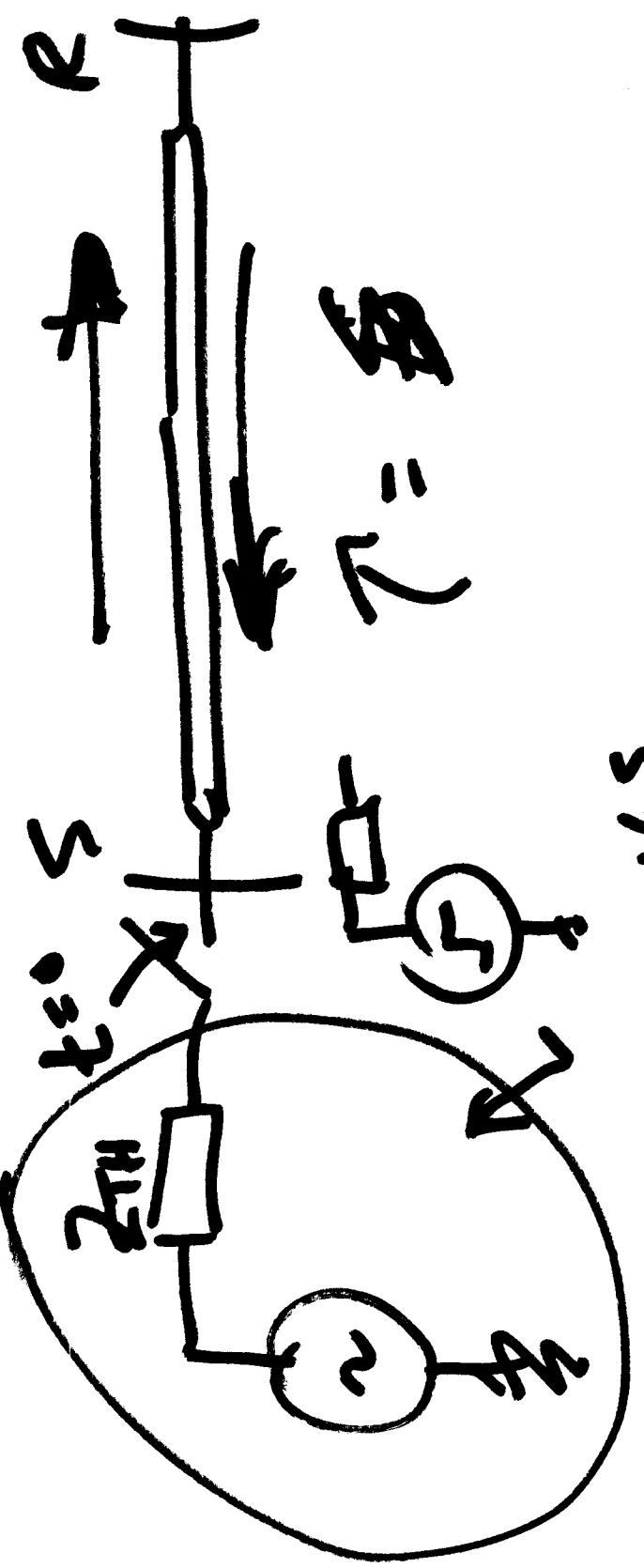
Voltage Reflection Coefficient:

$$\frac{V_R^-}{V_R^+} = \frac{Z_R - Z_C}{Z_R + Z_C} = \rho_s$$

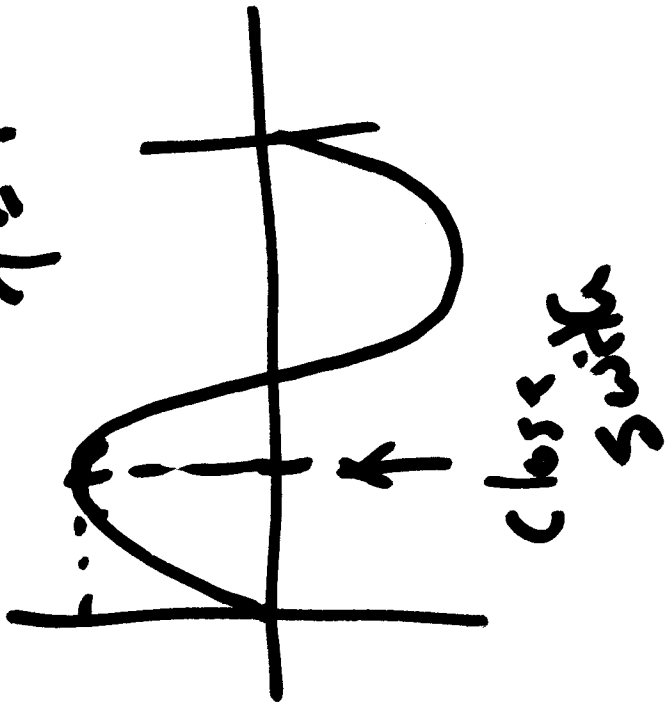
Current Reflection Coefficient

$$\frac{i_R^-}{i_R^+} = -\frac{V_R^-}{V_R^+} = -\rho_s$$





$\tau = 0.165$



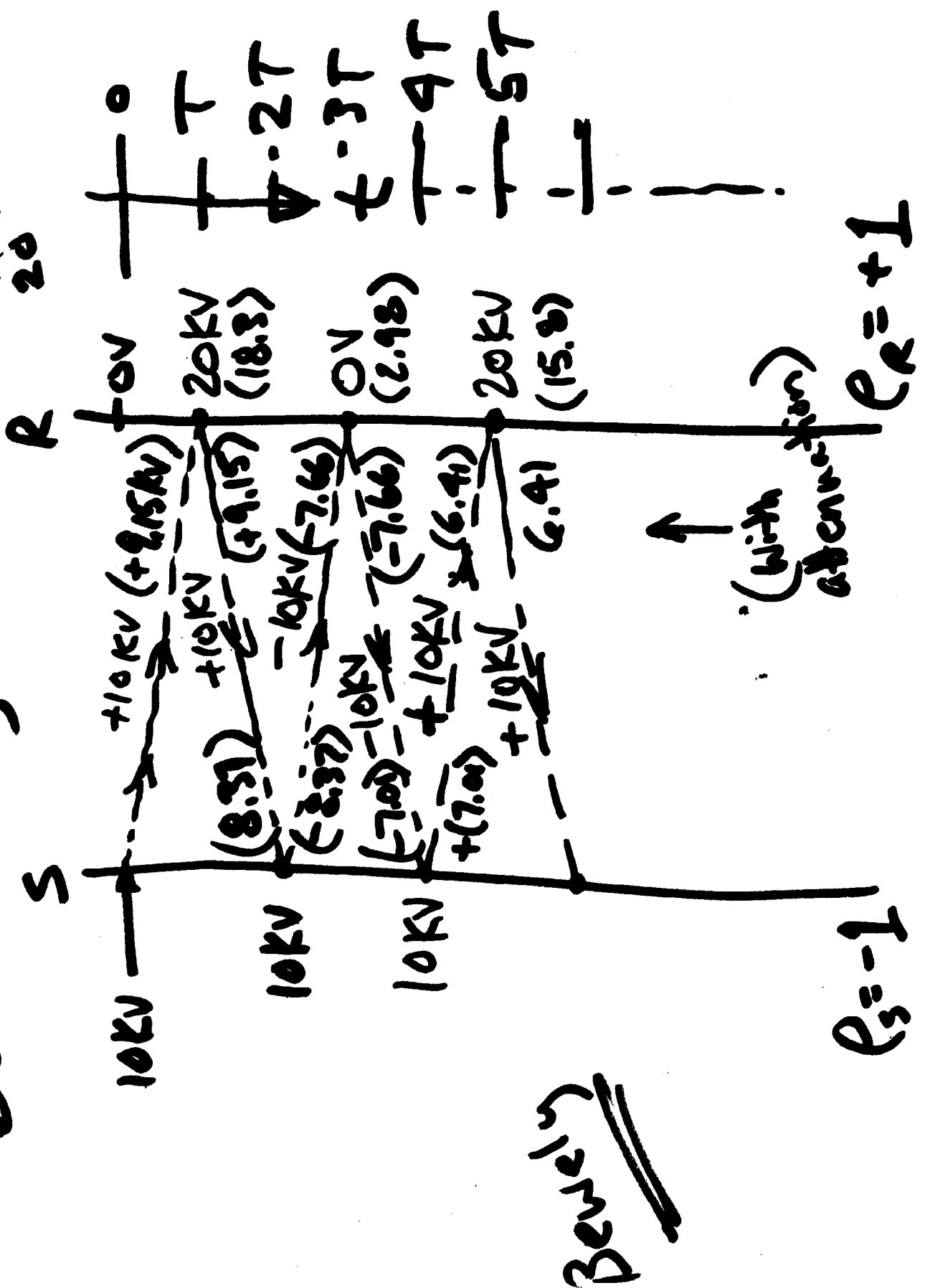
$\tau = 0.165$



"Bounce Diagrams"

Refer to end of Lecture notes...

20



Bounce