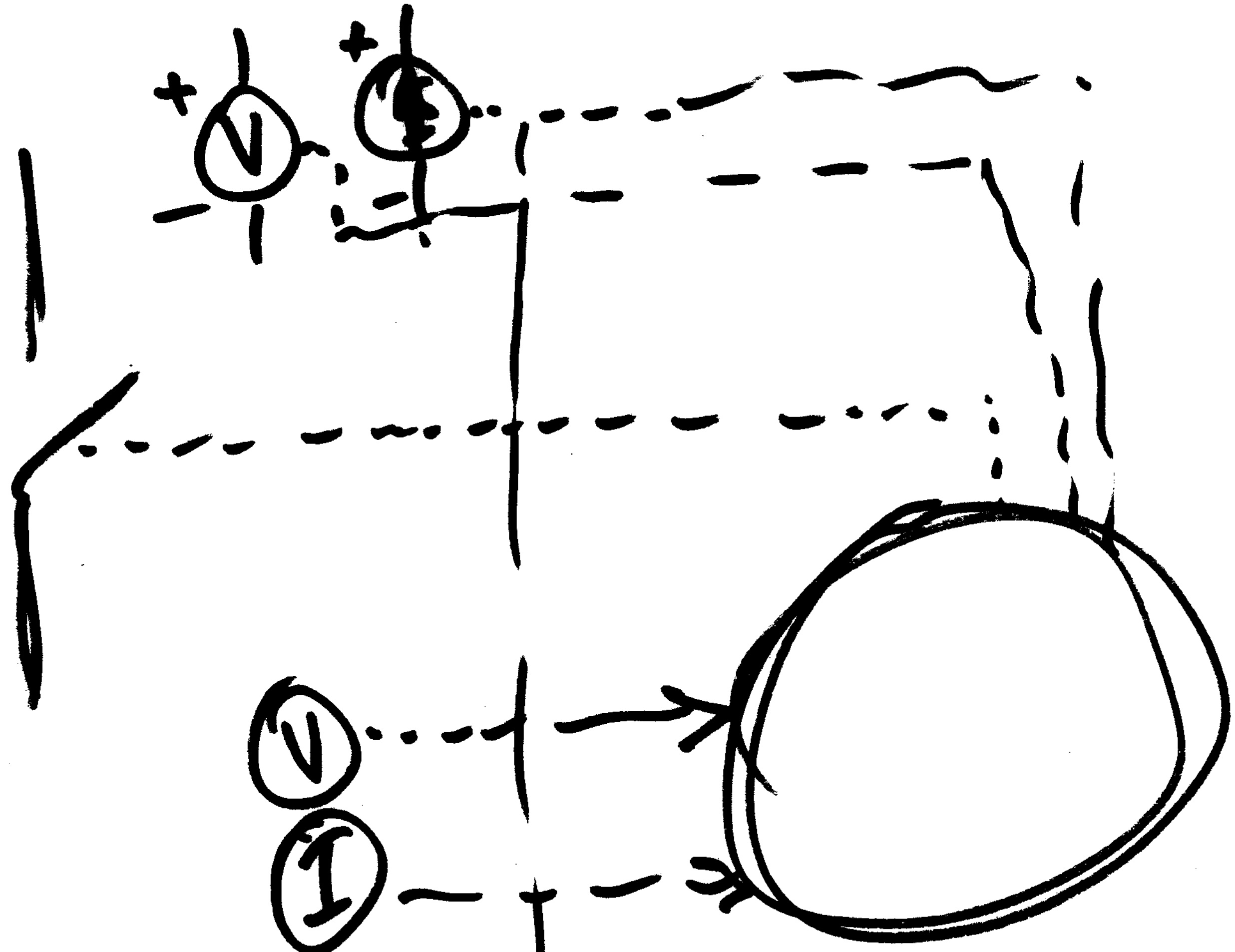
EE 5220 - Lecture 17 Wednesday Feb 16, 2022

Topics for Today:

- Course Info:
  - 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 = half letter grade, 5%)

- HW#5 is a partnered exercise. Due latest Feb 22nd 9am.
  - Section 12.4 - detailed derivation for capacitor
  - Prob 5.3 - suggest first do ATP simulation, then Hand Calculations
  - Prob 5.6
- HW#6 - due ~Mar 1st 9am.
- Term Project - proposed topic(s) by end of Week 6, via short e-mail.
- Transmission Lines
  - Recap of T-Line equations
  - Meaning and application of T-Line equations
    - Steady-state phasor calculations, ABCD parameters.
    - Traveling wave calculations
    - Propagation constant, Zc, etc.
- Use of ATPDraw's Line Constants to obtain parameters, build line models.
  - Review of EE5200 Week 6 (mainly Lectures 17-18)

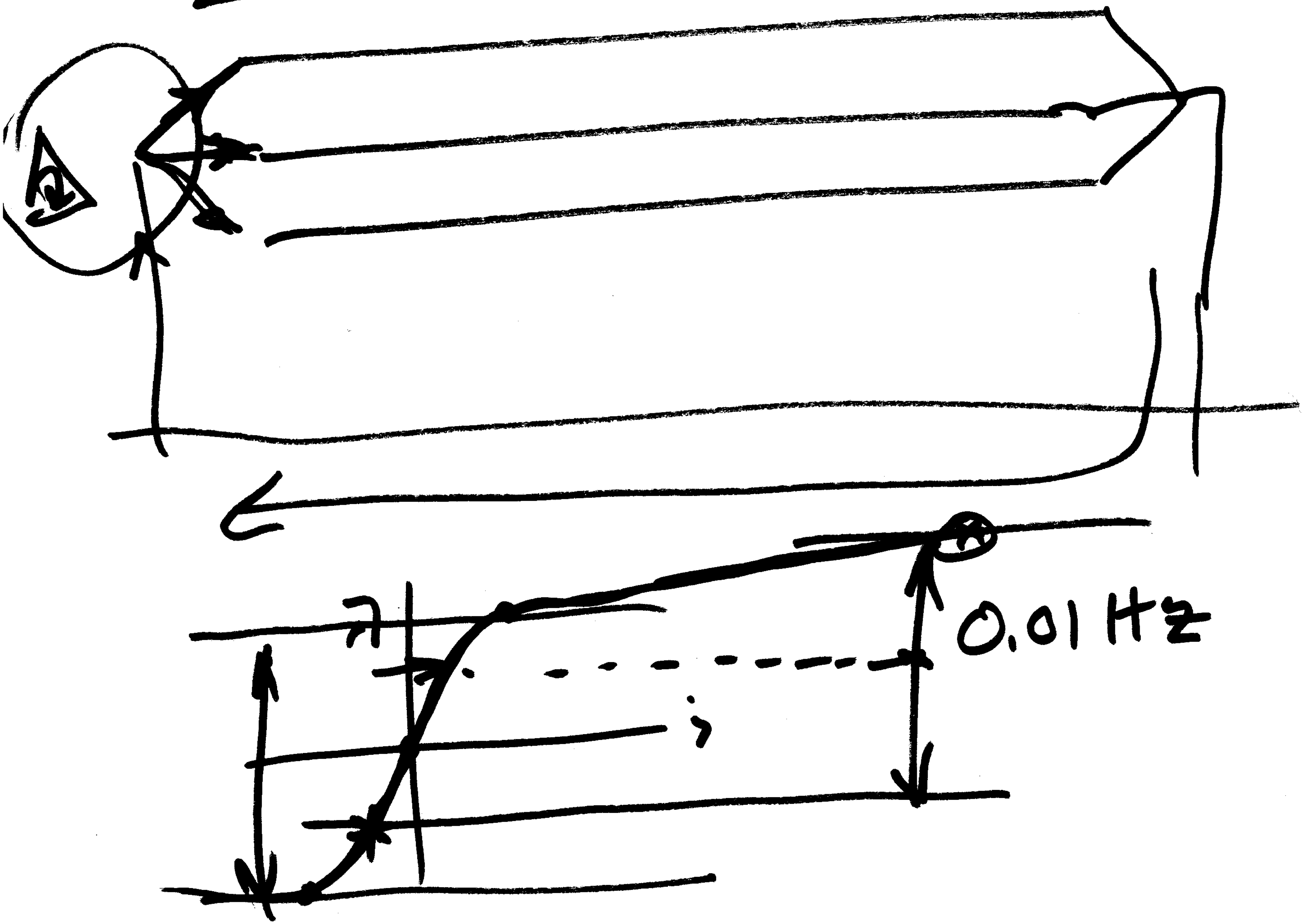


Circuits

Controls

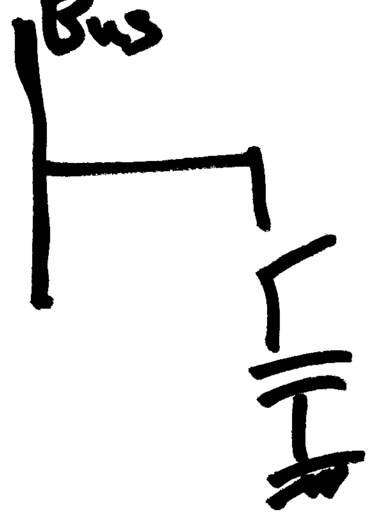
- TACS – GUI
- MODELS – CODE

GIC



Compensation

Shunt



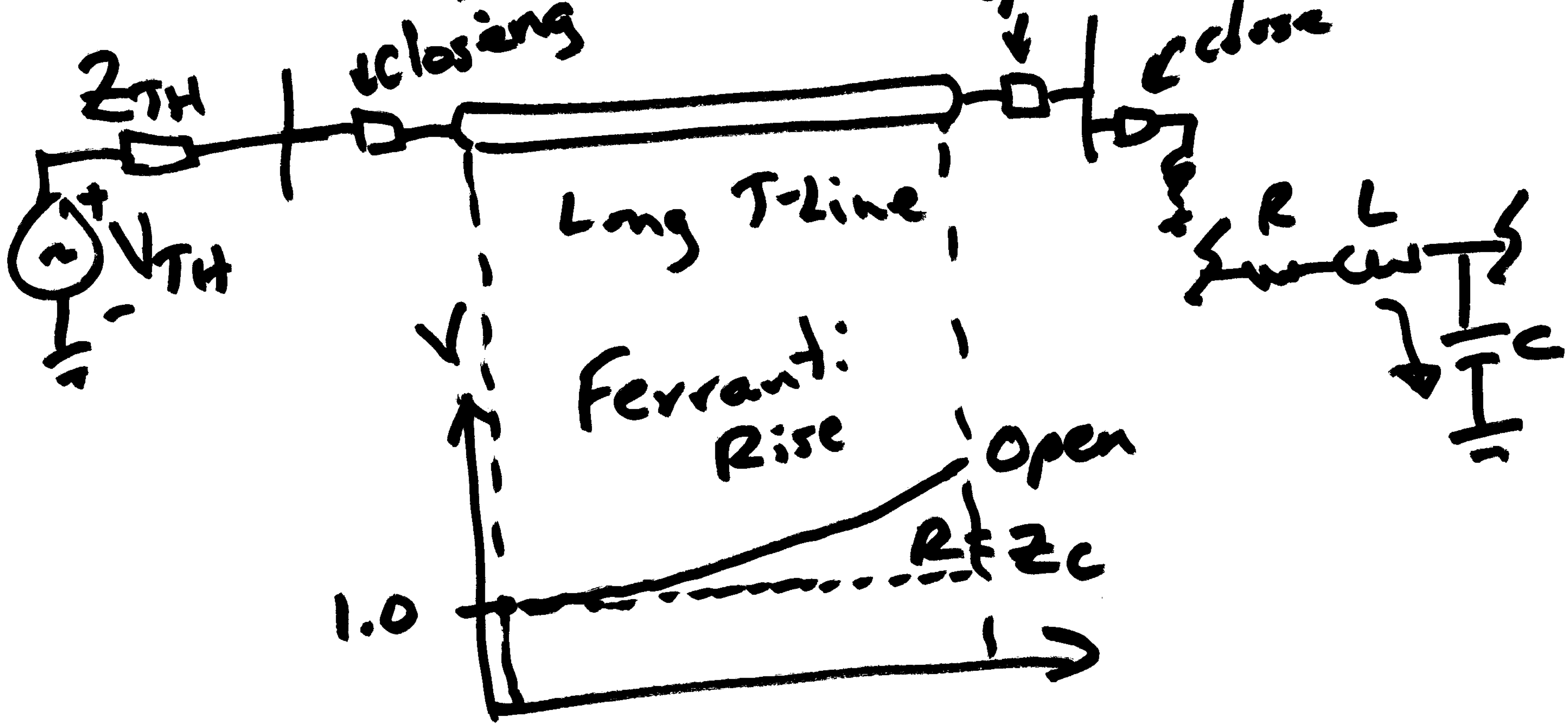
- Voltage Support
- Power Transfer

$$P_{1\text{-}2} = \frac{V_1 V_2}{X_{12}} \sin(\delta_1 - \delta_2)$$

21% increase
(.95 → 1.05 p.u. V)

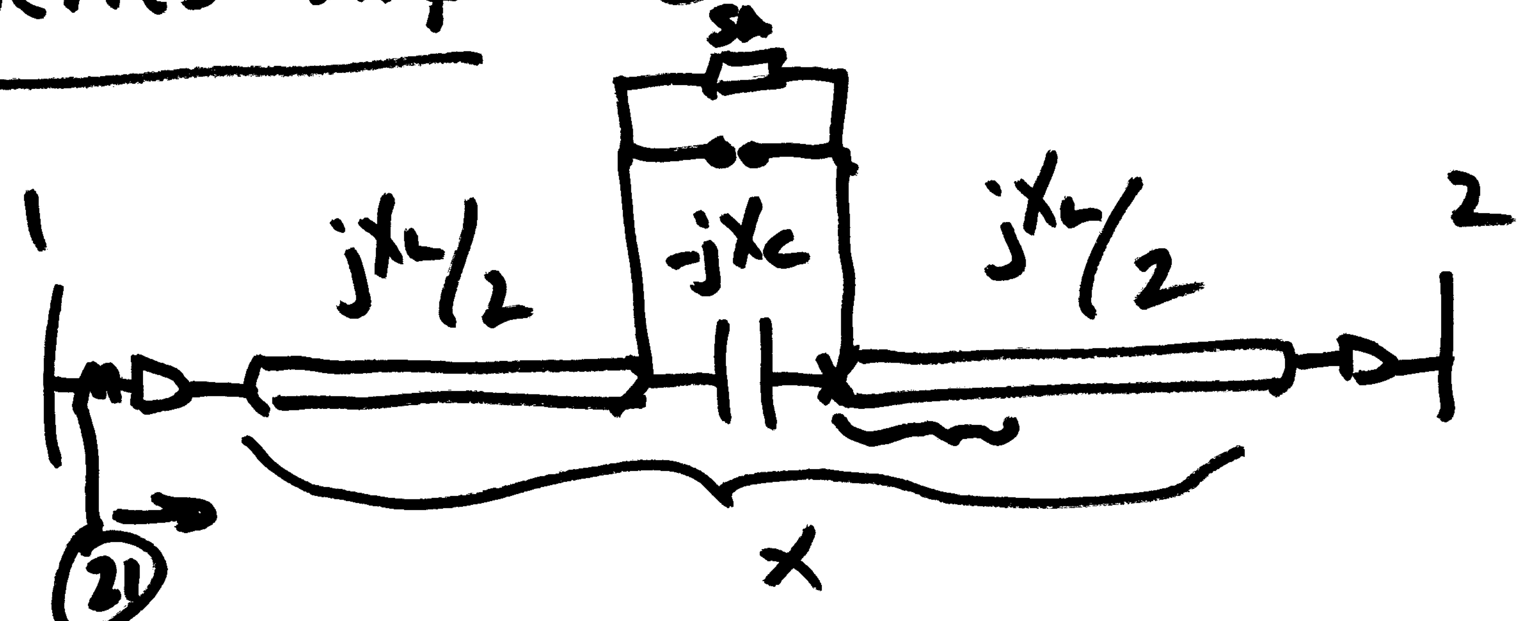
- Stability

Shunt Comp: Reactors



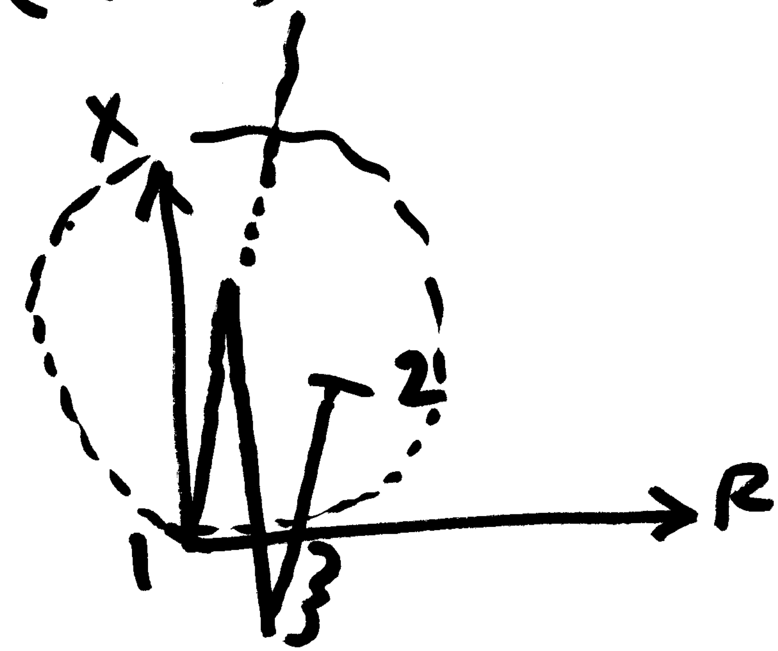
Ref: EE5200

Series Comp : C_{SR}

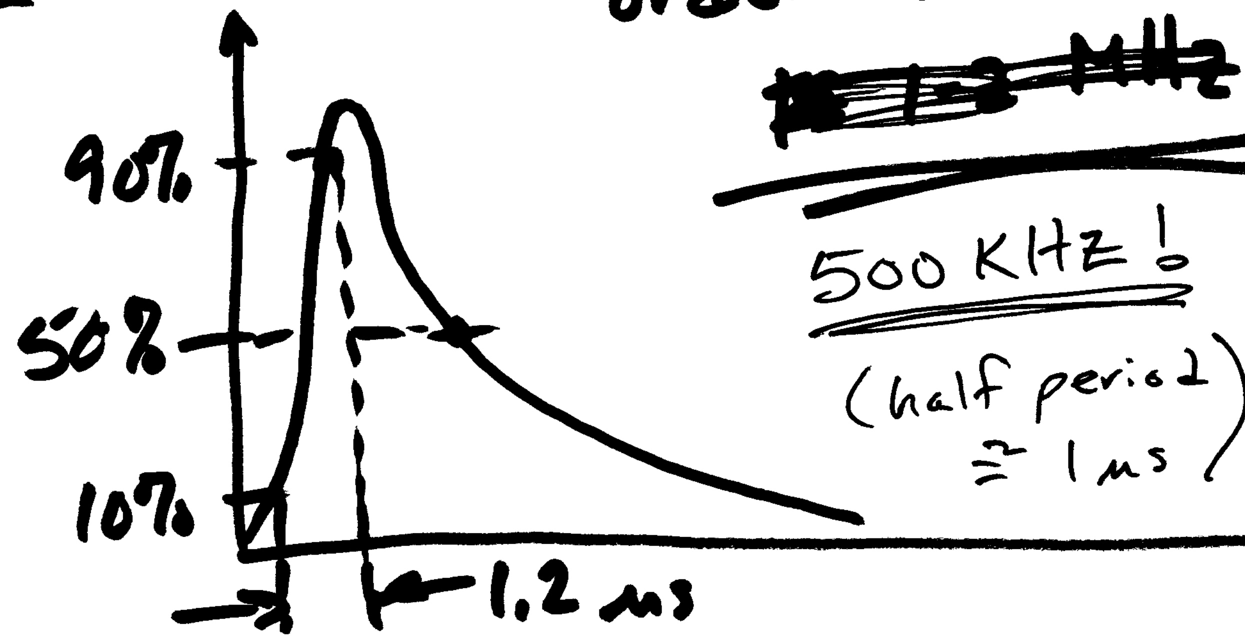


$$P_{1-2} = \frac{V_1 V_2}{X} \sin(\delta_1 - \delta_2)$$

$X_L - X_C$



Lightning –



order of

500 KHZ !

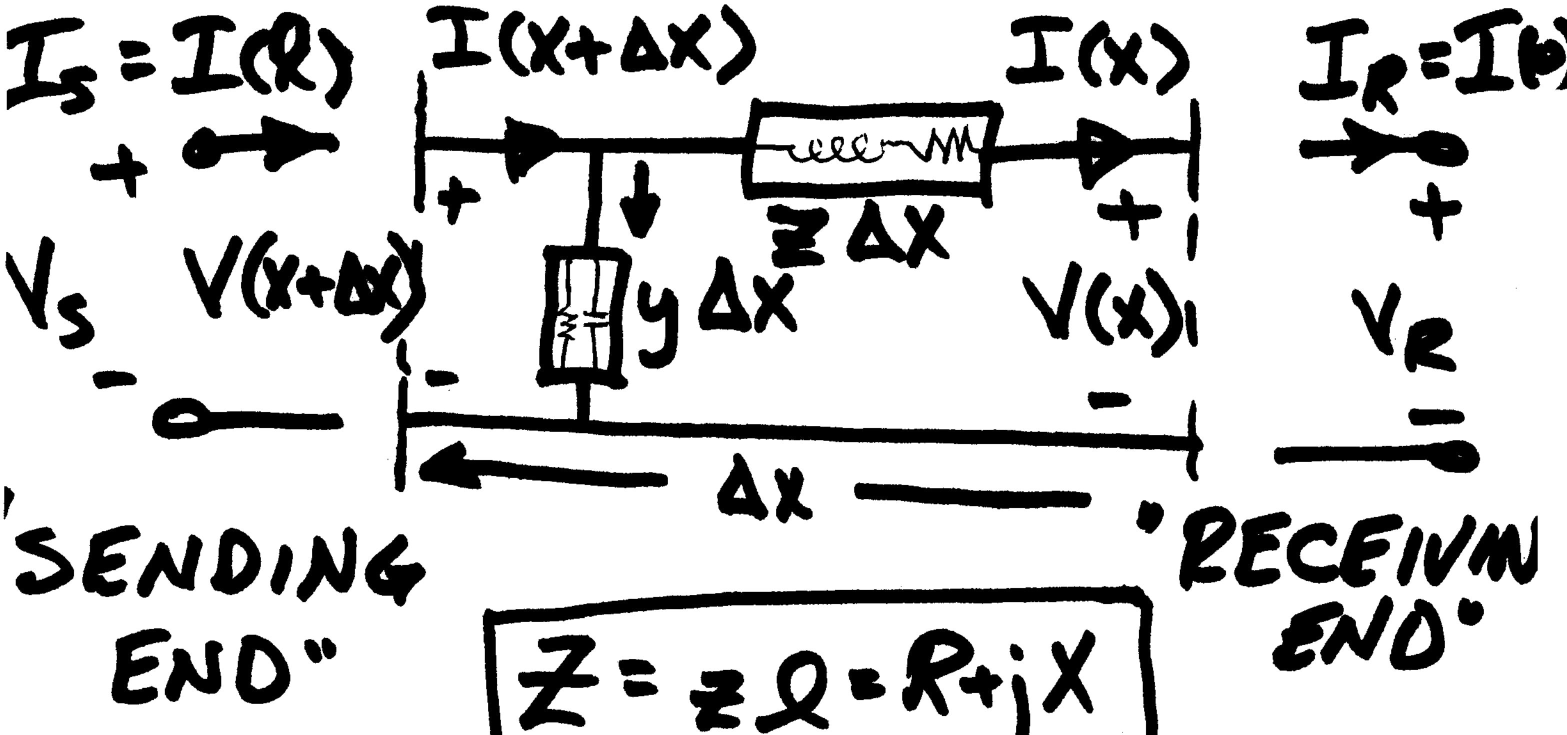
(half period ≅ 1 μs)

Switching –

DISTRIBUTED - PARAMER T-LINES

- "LONG LINES" (>250km @ 60Hz)
- FOR LIGHTNING, EVEN VERY SHORT LINES ARE MODELED AS DIST-PARAM.

FOR INCREMENTAL LENGTH:



$$\boxed{\begin{aligned} Z &= z\ell = R + jX \\ Y &= y\ell = G + jB \end{aligned}}$$

Making ΔX very small,

(small z)

$$\begin{cases} dV = IZ\,dx \\ dI = Vy\,dx \end{cases}$$

Rearranging,

$$\begin{cases} \dfrac{dV}{dx} = Iz & (1) \\ \quad \downarrow d/dx & \\ \dfrac{dI}{dx} = Vy & (2) \end{cases}$$

Taking derivative of (1),

$$\frac{d^2V}{dx^2} = \frac{dI}{dx} z$$

Substituting into (2)

$$\boxed{\frac{d^2 V}{dx^2} = V yz}$$

This implies gen'l sol'n:

$$V = A_1 e^{\sqrt{yz}\,x} + A_2 e^{-\sqrt{yz}\,x}$$

Since $I = \frac{dV}{dx} / Z$

$$I = A_1 \sqrt{\frac{y}{z}}\, e^{\sqrt{yz}\,x} - A_2 \sqrt{\frac{y}{z}}\, e^{-\sqrt{yz}\,x}$$

at $x = 0$, $V = V_R$, $I = I_R$

$$V(0) = V_R = A_1 + A_2$$

$$I(0) = I_R = \sqrt{\frac{y}{z}} A_1 - \sqrt{\frac{y}{z}} A_2$$

Defining $Z_c = \sqrt{\frac{z}{y}}$ = Char Imp.

$\gamma = \sqrt{yz}$ = Propagation Const.

$$\boxed{\begin{aligned} V_R &= A_1 + A_2 \\ I_R &= \frac{A_1 - A_2}{Z_c} \end{aligned}}$$

$$\Longrightarrow \quad A_1 = (V_R + Z_c I_R)/2$$

$$A_2 = \frac{V_R - Z_c I_R}{2}$$

$$V(x) = \frac{(V_R + Z_c I_R)}{2} e^{\gamma x} + \frac{(V_R - Z_c I_R)}{2} e^{-\gamma x}$$

$$I(x) = \left(\frac{V_R + Z_c I_R}{2 Z_c}\right) e^{\gamma x} - \left(\frac{V_R - Z_c I_R}{2 Z_c}\right) e^{-\gamma x}$$

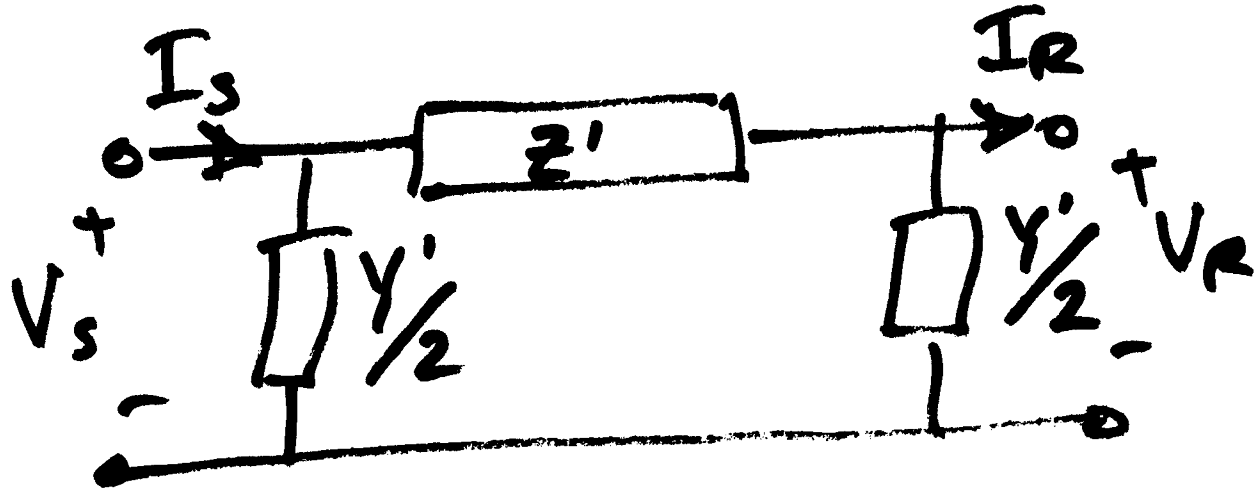
$$V_s = V(\ell) \leftarrow \underline{\underline{x = \ell}}$$

$$I_s = I(\ell)$$

$$V(x) = V_R \underbrace{\cosh(\gamma x)}_{A} + Z_c I_R \underbrace{\sinh(\gamma x)}_{B}$$

$$I(x) = \underbrace{\frac{V_R}{Z_c} \sinh(\gamma x)}_{C} + I_R \underbrace{\cosh(\gamma x)}_{D}$$

In hyperbolic form,



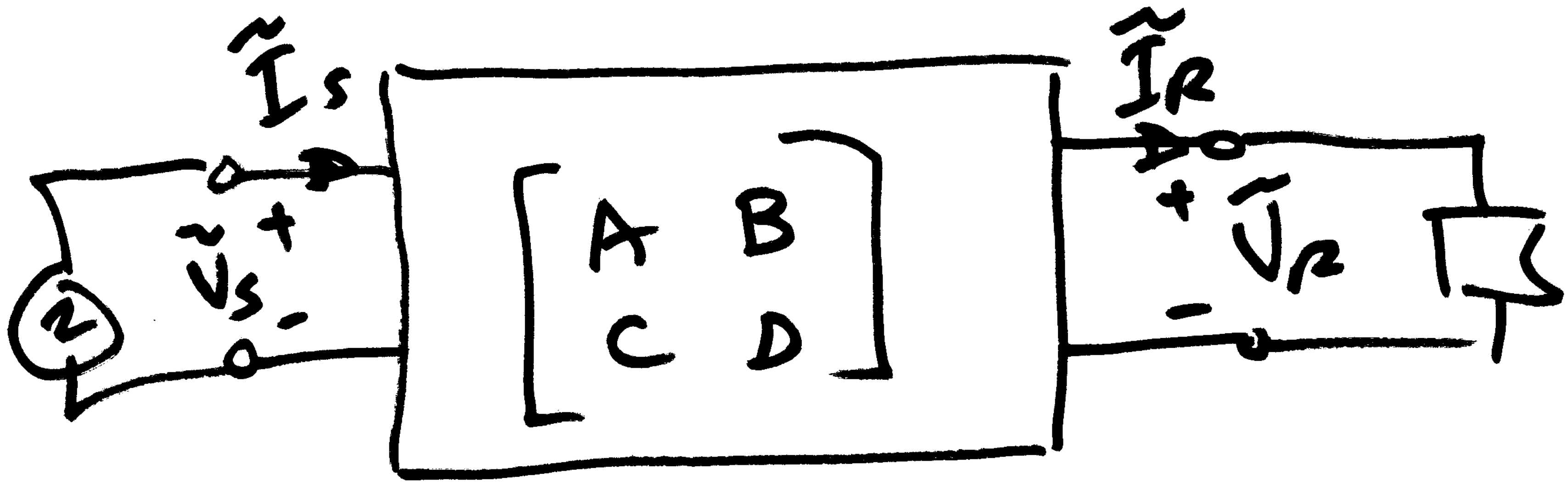
From EQNs:

$$\begin{bmatrix} V_S \\ I_S \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} V_R \\ I_R \end{bmatrix}$$

If we match $\begin{bmatrix} A & B \\ C & D \end{bmatrix}$ with π-Equiv

$$Z' = Z\left[\frac{\sinh(\gamma l)}{\gamma l}\right]$$

$$\frac{Y'}{2} = \frac{Y'}{2}\left[\frac{\tanh(\gamma l/2)}{\gamma l/2}\right]$$



per-phase T-Line

Propagation Constant

$$\gamma = \sqrt{yz} = \alpha + j\beta$$

α = attenuation constant (nepers/m)

β = phase constant (radians/m)

Referring to p. 8, exponential form of $V(x)$ & $I(x)$.

$$V(x) = V^{+}(x) + V'(x)$$

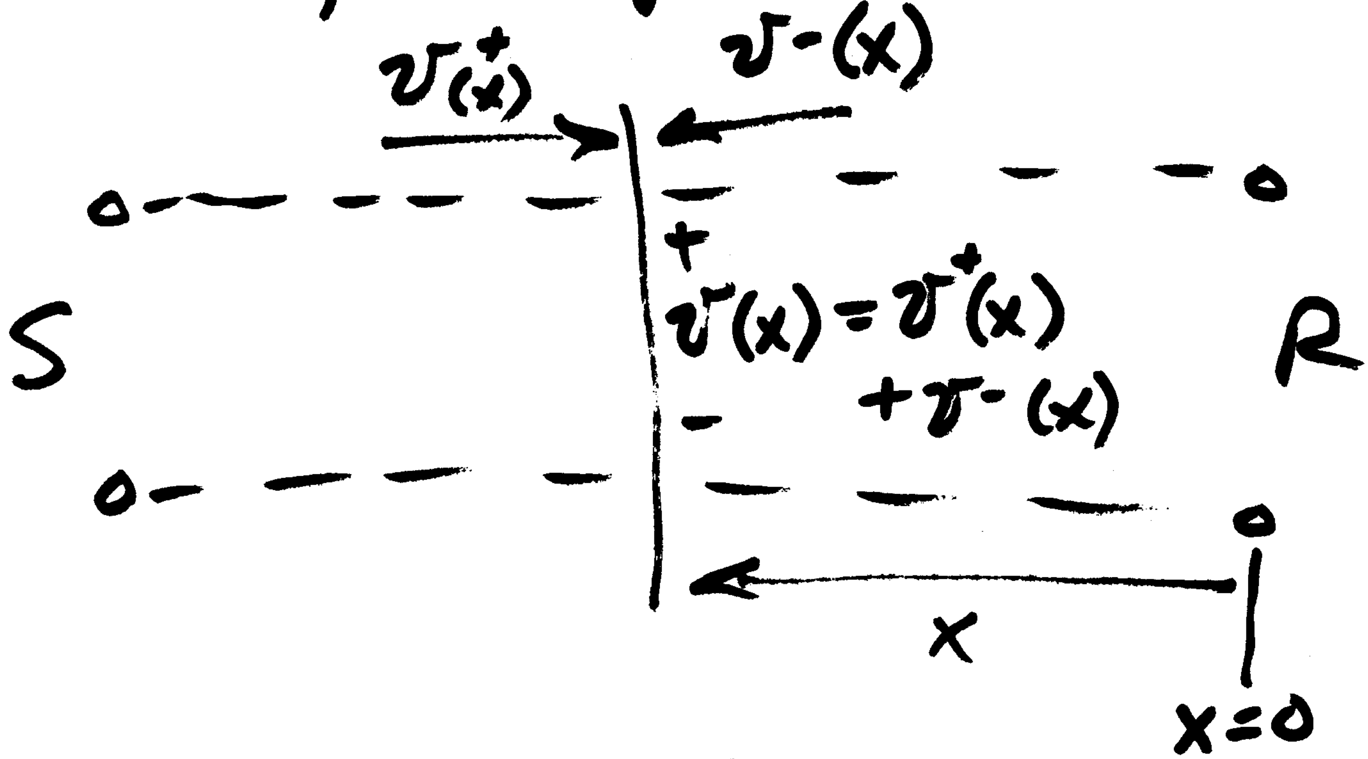
INCIDENT:

$$V^{+}(x) = \frac{V_R + I_R Z_c}{2} e^{+\alpha x} e^{+j\beta x}$$

REFLECTED:

$$V^{-}(x) = \frac{V_R - I_R Z_c}{2} e^{-\alpha x} e^{-j\beta x}$$

Conceptually



Same thing w/I's

$$I^+(x) = \left(\frac{V_R + Z_c I_R}{2 Z_c}\right) e^{\alpha x} e^{j\beta x}$$

$$I^-(x) = -\left(\frac{V_R - Z_c I_R}{2 Z_c}\right) e^{-\alpha x} e^{-j\beta x}$$

$(Z_R = Z_c)$

- SIL: Surge Imp Loading
- $\lambda = \frac{2\pi}{\beta}$ $\qquad e^{-j\beta x}$
- ~~β~~ $v = f\lambda$

@ 60 Hz: $\lambda = 3038$ mi

$v = 182{,}300$ mi/s

see following pages for add'l notes and a numerical ~~ex~~ example for a 3-phase line.

Look at γ

$$\gamma = \alpha + j\beta$$

α = attenuation constant
β = phase constant

$$V = \frac{V_R + I_R Z_c}{2} e^{\alpha x} e^{j\beta x} + \frac{V_R - I_R Z_c}{2} e^{-\alpha x} e^{-j\beta x}$$

$$I = \frac{\frac{V_R}{Z_c} + I_R}{2} e^{\alpha x} e^{j\beta x} - \frac{\frac{V_R}{Z_c} - I_R}{2} e^{-\alpha x} e^{-j\beta x}$$

Magnitude of
$e^{\alpha x}$ & $e^{-\alpha x}$ change with distance x which makes magnitude of V & I vary.

$e^{j\beta x}$ & $e^{-j\beta x}$ ~~...~~ change only in angle ~~...~~ as x changes. $|e^{j\beta x}| = |e^{-j\beta x}| = 1$

$$V_s^+ = \frac{V_R + I_R Z_c}{2} e^{\alpha x} e^{j\beta x}$$ = incident voltage that strikes receiving end

$$V_s^- = \frac{V_R - I_R Z_c}{2} e^{-\alpha x} e^{-j\beta x}$$ = reflected voltage reflected back from receiving end

If Load on line = Z_c, then reflected voltage = 0 ($\frac{V_R}{I_R} = Z_c$). This is called a flat line or infinite line. Normally this never occurs and it is impractical to attempt to do this.

For power systems, $Z_c = \sqrt{\frac{z}{y}}$ = surge impedance

if $R_{LINE} = 0$ $\quad Z_c = \sqrt{\frac{L}{C}}$

if $R_{LOAD} = |Z_c|$ then the reactive power supplied/consumed by line $= 0$

$$\frac{V^2}{X_c} = I^2 X_L \qquad \frac{V}{I} = \sqrt{X_L X_c} = \sqrt{\frac{L}{C}}$$

This is called <u>surge impedance loading</u>

Load is purely resistive $\quad R_L = \sqrt{\frac{L}{C}}$

$$|I_L| = \frac{V_L}{\sqrt{3}}\left(\frac{1}{\sqrt{\frac{L}{C}}}\right) \text{ Amps}$$

$$SIL = \sqrt{3}\,|V_L|\,|I_L|$$

$$= \sqrt{3}\,|V_L|\left(\frac{|V_L|}{\sqrt{3}}\ \frac{1}{\sqrt{\frac{L}{C}}}\right) = \boxed{\frac{|V_L|^2}{\sqrt{\frac{L}{C}}}\ MW}$$

where V is in k

Sometimes SIL is given in p.u.

wavelength

$$\lambda = \frac{2\pi}{\beta} \cong 3000 \text{ miles @ } 60 \text{ Hz}$$

$$v = f\lambda \cong \text{speed of light}$$

$$v = \frac{\omega}{\beta} = \frac{1}{\sqrt{\mu\varepsilon}}$$

EX: GROSSBEAK $D_{EQ} = 15$ ft. $\ell = 300$ mi

100 MW 200 KV_{L-L} PF = 1

$X_L = .412 + .3286 = .7406\ \Omega/mi$

$L = 1.965$ mH/mi

$X_C = .0946 + .0803$ MΩ-mi = .1747 MΩ-mi

$C = .01518\ \mu F/mi$

$R = .1454\ \Omega/mi$

$z = .1454 + j.7406 = .7547 \angle 78.9°\ \Omega/mi$

$y = 5.724 \times 10^{-6} \angle 90°$ ℧/mi $= \frac{1}{X_c}$

$\gamma\ell = \sqrt{yz}\,\ell = .6235 \angle 84.45° = \underbrace{\boxed{.0603}}_{\alpha\ell} + \underbrace{\boxed{j.6205}}_{j\beta\ell}$

$Z_c = \sqrt{\frac{z}{y}} = 363 \angle -5.5°\ \Omega$

$V_R = 200/\sqrt{3} = 115.2 \angle 0°$ KV

$I_R = 100 \times 10^6 / \sqrt{3}\,(200K) = 288.6 \angle 0°$ A

INCID. $V_R^+ = \dfrac{V_R + I_R Z_c}{2} = 109.85 \angle -2.62°$ KV

REFL. $V_R^- = \dfrac{V_R - I_R Z_c}{2} = 7.42 \angle 42.57°$ KV

INCID $V_s^+ = \dfrac{V_R + I_R Z_c}{2} e^{\alpha\ell} e^{j\beta\ell} = 116.68 \angle 32.93°$ KV

REFL. $V_s^- = \dfrac{V_R - I_R Z_c}{2} e^{-\alpha\ell} e^{-j\beta\ell} = 6.986 \angle 70.18°$ KV

$V_{LOAD} = V_R^+ + V_R^- = 115.2 \angle 0°$ KV ∴ checks ok

$V_s = V_s^+ + V_s^- = 123.04 \angle 31.5°$ KV

$\beta = \overset{\text{Phase}}{\text{Constant}} = .002068 \text{ Rad/mi}$

$\lambda = \frac{2\pi}{\beta} = 3038 \text{ miles}$

$V = F\lambda = 182{,}300 \text{ mi/sec}$

$I_s^+ = \frac{V_s^+}{Z_c} = 321.43 \angle 38.43^\circ \text{ A}$

$I_s^- = \frac{V_s^-}{Z_c} = -19.24 \angle 112.518^\circ \text{ A}$

$I_s = I_s^+ + I_s^- = 304.2 \angle 40.01^\circ$

$MVA = \sqrt{3} V_{LS} I_{LS} = \sqrt{3} \left(\cancel{213.04}\right)(304.2) =$

(213.04)

112.25 MVA

$P_s = 112.25 \cos(40.01 - 31.5) = \underline{111.26 \text{ MW}}$

$Q_s = \underline{-16.61 \text{ MVAR}}$

B.A. Mork **EE 5220 - HW#6** Spring 2020

T-Line Parameters & Modeling Due Mar 3rd

You may work with one homework partner on this if you wish. Using ATPDraw's Line Constants interface, you will enter the physical design dimensions of a single-circuit and a double-circuit line and obtain the parameters of the line, and use the Verify function to confirm the 60-Hz sequence impedances and line-charging MVA.

As with all of your work with ATP, refer to the 346-page ATPDraw Users Manual, this is available in the ATP program group on the remote.mtu.edu server. Many good examples and self-help / self-learning. Discussions on our e-mail group can be referring to appropriate pages of this manual.

For both cases, use the lumped parameter coupled-pi model, assume earth resistivity is 100 Ohm-meters, and create the model for 60-Hz. Check off all possible output requests – this will create a detailed output of all parameter matrices and line parameters in the *.lis file (in H:\atp\results\.

Case 1: See attached example 5.10 from Glover & Sarma 2nd Ed. However, use line data from EPRI case 3H4. http://www.ece.mtu.edu/faculty/bamork/ee5200/TLin_cfg.pdf If the required line data is not given in the attached table, look it up in mfrs web page (links via Useful Web Links).

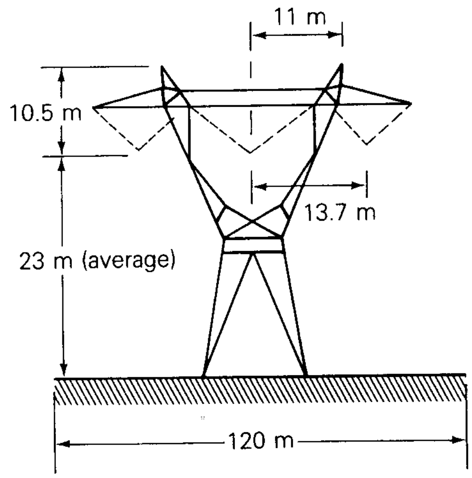
Case 2a: Do Prob. 5.37 from Glover & Sarma 2nd Ed. However, use line data from EPRI case 3P3.
Case 2b: Do Prob 5.38 from Glover & Sarma 2nd Ed. Again, use 3P3 line data.

For each case:
- Provide notes on how you handle the conductor parameters and in general how you used Line Constants.
- Copy/paste the parameter input screens from Line Constants. Provide annotations.
- Copy/paste the Verify output for steady-state 60Hz
  - Sequence impedances and line charging MVARs. Explain meaning of each. Elaborate on pos, neg, zero effects for impedance and line charging.
- Copy/paste the Frequency Scan Verify output for 1 Hz -100 kHz. Why are positive sequence and zero sequence different? Can you trust the Pi model at high frequencies?
- Copy/paste the Linecheck output for steady-state 60 Hz. Explore use of selecting output in different units. Explain meaning.
- Provide a printout of the .lis file's Line Constants output. Provide annotations of the meaning of each of the parameter matrices.
- From *.lis printout:
  - Make note of z & y in ohms and S per mile or per meter.
  - Make note of γ, α, β, Z_C, τ.
  - For the single-circuit line, calculate the line's ABCD parameters.

In the next homework, you can begin using the line model to simulate things like Ferranti Rise, traveling waves, line loading effects, and many other performance scenarios.

Figure 5.31

Three-phase 765-kV line for Example 5.10



Neutrals:
2—Alumoweld 7 no. 8
Radius = 0.489 cm
GMR = 0.0636 cm
Resistance = 1.52 Ω/km

Phase conductors:
4—ACSR 954 kcmil, 54/7
Radius = 1.519 cm
GMR = 1.229 cm
Resistance = 0.0701 Ω/km
Bundle spacing = 45.7 cm

Earth resistivity = 100 Ωm
Frequency = 60 Hz
Voltage = 765 kV

Table 5.6 Output data for Example 5.10

Series phase impedance matrix $\boldsymbol{Z}_P$ Eq. 5.7.19 Units:Ohms/km

$$\begin{bmatrix} 0.1181E+00+j5.532E-01 & 0.1009E+00+j2.340E-01 & 0.9813E-01+j1.842E-01 \\ 0.1009E+00+j2.339E-01 & 0.1200E+00+j5.500E-01 & 0.1009E+00+j2.339E-01 \\ 0.9813E-01+j1.842E-01 & 0.1009E+00+j2.340E-01 & 0.1181E+00+j5.532E-01 \end{bmatrix}$$

Series sequence impedance matrix $\boldsymbol{Z}_S$ Eq. 5.7.25 Units: Ohms/km

$$\begin{bmatrix} 0.3187E+00+j9.869E-01 & 0.1264E-00-j9.112E-03 & -.1421E-01-j6.389E-03 \\ -.1421E-01-j6.374E-03 & 0.1875E-01+j3.347E-01 & -.2903E-01+j1.814E-02 \\ 0.1262E-01-j9.117E-03 & 0.3022E-01+j1.607E-02 & 0.1875E-01+j3.347E-01 \end{bmatrix}$$

Shunt phase admittance matrix $\boldsymbol{Y}_P$ Eq. 5.11.16 Units: S/km

$$\begin{bmatrix} +j4.311E-06 & -j7.666E-07 & -j2.167E-07 \\ -j7.666E-07 & +j4.439E-06 & -j7.666E-07 \\ -j2.167E-07 & -j7.666E-07 & +j4.311E-06 \end{bmatrix}$$

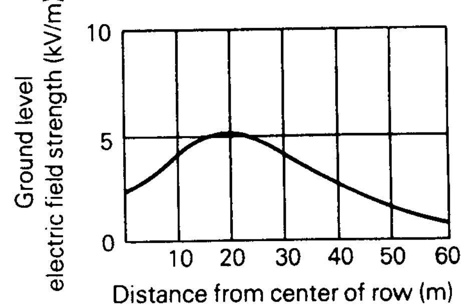
Shunt sequence admittance matrix $\boldsymbol{Y}_S$ Eq. 5.11. 19 Units: S/km

$$\begin{bmatrix} 0.0000E+00 & +j3.187E-06 & -.1219E-06 & +j7.036E-08 & 0.1219E-06 & +j7.036E-08 \\ 0.1219E-06 & +j7.036E-08 & -.3901E-13 & +j4.937E-06 & 0.3544E-06 & -j2.046E-07 \\ -.1219E-06 & +j7.036E-08 & -.3544E-06 & -j2.046E-07 & 0.3901E-13 & +j4.937E-06 \end{bmatrix}$$

Conductor surface electric field strength Eqs. 5.12.1–5.12.5

$E_{r\max} = 19.3\,\mathrm{kV_{rms}/cm}$

Lateral profile of ground-level electric field strength Eq. 5.12.6



■

5.31 Rework Problem 5.30 with one neutral wire located 6 m directly above the center phase conductor. Compare the series sequence impedance matrix with that of Problem 5.30.

5.32 Using the LINE CONSTANTS program, compute the shunt sequence admittance matrix for the line in Problem 5.13. Assume an average line height of 20 m and no neutral wires. Compare the computed positive-sequence shunt admittance with the result calculated in Problem 5.21.

5.33 Rework Problem 5.32 with two neutral wires located 7 m above and 8 m to the left and right of the center bundle.

5.34 Using the LINE CONSTANTS program, compute the conductor surface electric field strength and the ground-level electric field strength profile for the line in Problem 5.33. Assume a 100 m right-of-way width.

5.35 Determine the effect of a 10% decrease as well as a 10% increase in phase spacing on the conductor surface electric field strength and on the ground-level electric field strength profile for the line in Problem 5.34.

5.36 Determine the effect of a 10% decrease as well as a 10% increase in the average line height on the conductor surface electric field strength as well as the ground-level electric field strength profile for the line in Problem 5.34.

5.37 Using the LINE CONSTANTS program, calculate the equivalent series sequence impedance matrix and the equivalent shunt sequence admittance matrix for the double-circuit, three-phase line shown in Figure 5.34 with phase arrangement I.

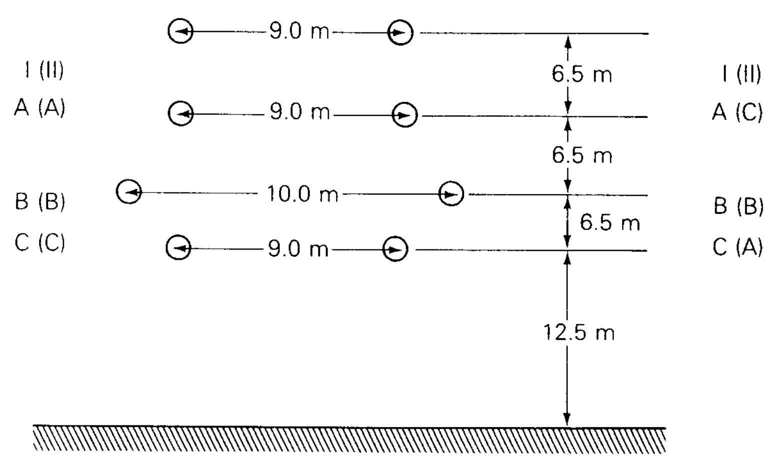
Figure 5.34

Double-circuit line for Problems 5.37 and 5.38

Phase conductors:
1—ACSR 2515 kcmil, 76/19
Radius = 2.388 cm
GMR = 1.893 cm
Resistance = 0.0280 Ω/km

Neutrals:
2—Alumoweld 7 no. 8
Radius = 0.489 cm
GMR = 0.0636 cm
Resistance = 1.52 Ω/km

Earth resistivity = 100 Ωm
Frequency = 60 Hz
Voltage = 345 kV



5.38 Rework Problem 5.37 for phase arrangement II shown in parentheses in Figure 5.34. Compare the computed results of the two phase arrangements.

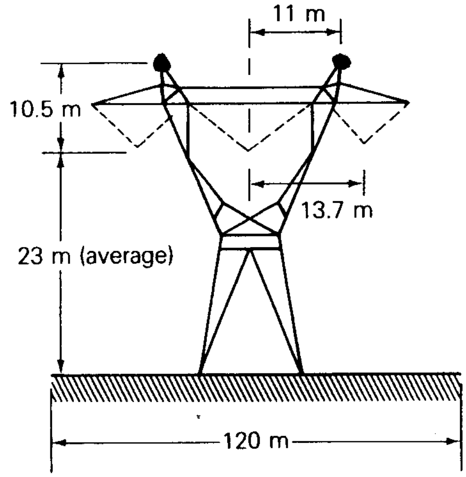
Rdc (r')

CONDUCTOR	SIZE (KCM)	AL/STL	AREA (SI)	DIAM (IN)	WEIGHT (LB/FT)	RATED STREN (LBS)	L OHMS /MI	C MOHM /MI	R-25C OHMS /MI	R-50C OHMS /MI	CHART #	GMR (FT)	% WT ALUM
TURKEY	26.2	6/ 1	.0240	.198	.036	1190	.636	.1423	3.4590	3.9400	1-1023	.0053	67.90
SWAN	41.7	6/ 1	.0383	.250	.057	1860	.604	.1353	2.1780	2.5180	1-1023	.0069	67.90
SWANATE	41.7	7/ 1	.0411	.257	.067	2360	.608	.1346	2.1540	2.5230	1-670	.0067	58.10
SPARROW	66.4	6/ 1	.0608	.316	.091	2850	.578	.1284	1.3720	1.6280	1-1023	.0085	67.90
SPARATE	66.4	7/ 1	.0653	.325	.107	3640	.579	.1276	1.3570	1.6350	1-1023	.0085	58.10
GROUSE	80.0	8/ 1	.0847	.370	.149	5200	.570	.1240	1.1200	1.4040	1-430	.0091	50.40
ROBIN	83.8	6/ 1	.0767	.355	.115	3550	.564	.1250	1.0890	1.3050	1-938	.0096	67.90
PETREL	101.8	12/ 7	.1266	.461	.254	10400	.540	.1172	.8510	1.0840	1-546	.0117	37.80
RAVEN	105.7	6/ 1	.0967	.398	.145	4380	.550	.1216	.8640	1.0520	1-938	.0108	67.90
MINORCA	110.8	12/ 7	.1378	.481	.277	11300	.535	.1160	.8010	1.0240	1-546	.0122	37.80
QUAIL	133.2	6/ 1	.1219	.447	.183	5310	.536	.1186	.6860	.8530	1-938	.0121	67.90
LEGHORN	134.6	12/ 7	.1674	.530	.336	13600	.525	.1131	.6460	.8450	1-546	.0132	37.80
GUINEA	159.0	12/ 7	.1977	.576	.397	16000	.516	.1106	.5470	.7310	1-546	.0142	37.80
PIGEON	167.7	6/ 1	.1538	.502	.231	6620	.520	.1147	.5450	.6900	1-938	.0137	67.90
DOTTEREL	176.9	12/ 7	.2200	.607	.441	17300	.509	.1091	.4930	.6670	1-546	.0151	37.80
DORKING	190.8	12/ 7	.2373	.631	.476	18700	.504	.1079	.4570	.6250	1-546	.0157	37.80
BRAHMA	203.2	16/19	.3020	.714	.667	20700	.489	.1043	.4120	.5530	1-546	.0178	28.30
COCHIN	211.3	12/ 7	.2628	.663	.528	28400	.498	.1065	.4130	.5750	1-546	.0165	37.80
PENGUIN	211.6	6/ 1	.1939	.563	.291	8350	.508	.1113	.4340	.5690	1-938	.0152	67.90
WAXWING	266.8	18/ 1	.2211	.609	.289	6880	.476	.1090	.3488	.3831	1-844	.0198	86.45
PARTRIDGE	266.8	26/ 7	.2436	.642	.367	11300	.465	.1074	.3452	.3792	1-782	.0217	68.60
OSTRICH	300.0	26/ 7	.2740	.680	.413	12700	.458	.1057	.3070	.3372	1-782	.0229	68.60
MERLIN	336.4	18/ 1	.2789	.684	.365	8680	.462	.1055	.2767	.3037	1-844	.0222	86.45
LINNET	336.4	26/ 7	.3072	.721	.463	14100	.451	.1040	.2737	.3006	1-782	.0243	68.60
ORIOLE	336.4	30/ 7	.3259	.741	.527	17300	.445	.1032	.2719	.2987	1-773	.0255	60.35
CHICKADEE	397.5	18/ 1	.3295	.743	.432	9940	.452	.1031	.2342	.2572	1-844	.0241	86.45
BRANT	397.5	24/ 7	.3527	.772	.512	14700	.444	.1018	.2367	.2600	1-889	.0259	73.25
IBIS	397.5	26/ 7	.3630	.783	.547	16300	.441	.1015	.2323	.2551	1-782	.0264	68.60
LARK	397.5	30/ 7	.3850	.806	.623	20300	.435	.1007	.2306	.2533	1-773	.0277	60.35
PELICAN	477.0	18/ 1	.3954	.814	.518	11800	.441	.1004	.1957	.2148	1-844	.0264	86.45
FLICKER	477.0	24/ 7	.4232	.846	.615	17200	.432	.0992	.1943	.2134	1-889	.0284	73.25
HAWK	477.0	26/ 7	.4356	.858	.657	19500	.430	.0988	.1931	.2120	1-782	.0289	68.60
HEN	477.0	30/ 7	.4620	.883	.747	23800	.424	.0980	.1919	.2107	1-773	.0304	60.35
OSPREY	556.5	18/ 1	.4614	.879	.604	13700	.432	.0981	.1679	.1843	1-844	.0284	86.45
PARAKEET	556.5	24/ 7	.4938	.914	.717	19800	.423	.0969	.1669	.1832	1-889	.0306	73.25
DOVE	556.5	26/ 7	.5083	.927	.766	22600	.420	.0965	.1663	.1826	1-782	.0314	68.60
EAGLE	556.5	30/ 7	.5391	.953	.872	27800	.415	.0957	.1651	.1812	1-773	.0327	60.35
PEACOCK	605.0	24/ 7	.5368	.953	.780	21600	.418	.0957	.1536	.1685	1-889	.0319	73.25
SQUAB	605.0	26/ 7	.5526	.966	.833	24300	.415	.0953	.1529	.1679	1-782	.0327	68.60
TEAL	605.0	30/19	.5835	.994	.940	30000	.410	.0944	.1517	.1665	1-757	.0341	60.90
KINGBIRD	636.0	18/ 1	.5272	.940	.691	15700	.424	.0960	.1484	.1627	1-844	.1915	86.45
ROOK	636.0	24/ 7	.5643	.977	.819	22000	.415	.0950	.1461	.1603	1-889	.0327	73.25
GROSBEAK	636.0	26/ 7	.5809	.990	.875	25200	.412	.0946	.1454	.1596	1-782	.0335	68.60
EGRET	636.0	30/19	.6134	1.019	.988	31500	.406	.0937	.1447	.1589	1-757	.0352	60.90
FLAMINGO	666.6	24/ 7	.5914	1.000	.859	23700	.412	.0943	.1397	.1533	1-889	.0335	73.25
CROW	715.5	54/ 7	.6340	1.036	.921	26300	.407	.0932	.1304	.1430	1-838	.0349	73.25
STARLING	715.5	26/ 7	.6535	1.051	.985	28400	.405	.0948	.1294	.1420	1-537	.0355	68.60
REDWING	715.5	30/19	.6901	1.081	1.111	34600	.399	.0920	.1287	.1412	1-757	.0373	60.90
CUCKOO	795.0	24/ 7	.7035	1.092	1.024	27900	.402	.0915	.1193	.1308	1-889	.0366	73.20
DRAKE	795.0	26/ 7	.7261	1.108	1.094	31500	.399	.0912	.1172	.1284	1-537	.0373	68.60
MALLARD	795.0	30/19	.7668	1.140	1.235	38400	.393	.0904	.1159	.1272	1-757	.0392	60.90
COOT	795.0	36/ 1	.6416	1.040	.805	16500	.411	.0930	.1197	.1311	1-898	.0337	92.70
TERN	795.0	45/ 7	.6676	1.063	.896	22100	.406	.0925	.1188	.1302	1-955	.0352	83.70
CONDOR	795.0	54/ 7	.7053	1.093	1.024	28200	.400	.0916	.1174	.1286	1-838	.0370	73.25
CRANE	874.5	54/ 7	.7766	1.146	1.126	31400	.395	.0902	.1073	.1176	1-838	.0386	73.25
RUDDY	900.0	45/ 7	.7555	1.131	1.015	25400	.399	.0905	.1062	.1163	1-955	.0374	83.70
CANARY	900.0	54/ 7	.7985	1.162	1.159	31900	.393	.0898	.1041	.1140	1-838	.0392	73.25
RAIL	954.0	45/ 7	.8011	1.165	1.075	25900	.395	.0897	.0997	.1092	1-955	.0386	83.70
CARDINAL	954.0	54/ 7	.8464	1.196	1.229	33800	.390	.0890	.0988	.1082	1-838	.0402	73.25
ORTOLAN	1033.5	45/ 7	.8678	1.213	1.165	27700	.390	.0885	.0924	.1011	1-957	.0402	83.70
CURLEW	1033.5	54/ 7	.9169	1.246	1.331	36600	.385	.0877	.0914	.1000	1-838	.0402	73.25
BLUEJAY	1113.0	45/ 7	.9346	1.259	1.255	29800	.386	.0874	.0861	.0941	1-957	.0415	83.70
FINCH	1113.0	54/19	.9849	1.293	1.431	39100	.380	.0866	.0856	.0937	1-1009	.0436	73.70
BUNTING	1192.5	45/ 7	1.0010	1.302	1.344	32000	.382	.0864	.0809	.0884	1-957	.0429	83.70
GRACKLE	1192.5	54/19	1.0550	1.338	1.533	41900	.376	.0856	.0798	.0873	1-1009	.0451	73.70
BITTERN	1272.0	45/ 7	1.0680	1.345	1.434	34100	.378	.0855	.0762	.0832	1-957	.0444	83.70
PHEASANT	1272.0	54/19	1.1260	1.382	1.635	43600	.372	.0847	.0751	.0821	1-1009	.0466	73.70
DIPPER	1351.5	45/ 7	1.1350	1.386	1.522	36200	.374	.0846	.0721	.0786	1-957	.0459	83.70
MARTIN	1351.5	54/19	1.1960	1.424	1.737	46300	.368	.0838	.0710	.0775	1-1009	.0482	73.70
BOBOLINK	1431.0	45/ 7	1.2020	1.427	1.613	38300	.371	.0837	.0684	.0746	1-957	.0470	83.70
PLOVER	1431.0	54/19	1.2660	1.465	1.840	49100	.365	.0829	.0673	.0735	1-1009	.0494	73.70
NUTHATCH	1510.5	45/ 7	1.2680	1.466	1.702	40100	.367	.0829	.0649	.0707	1-957	.0486	83.70
PARROT	1510.5	54/19	1.3370	1.506	1.942	51700	.362	.0821	.0643	.0701	1-1009	.0506	73.70
LAPWING	1590.0	45/ 7	1.3350	1.502	1.792	42200	.364	.0822	.0623	.0678	1-957	.0498	83.70
FALCON	1590.0	54/19	1.4070	1.545	2.044	54500	.358	.0814	.0612	.0667	1-1009	.0523	73.70
CHUKAR	1780.0	84/19	1.5120	1.602	2.074	51000	.355	.0803	.0560	.0609	1-1020	.0536	81.30
BLUEBIRD	2156.0	84/19	1.8310	1.762	2.511	60300	.344	.0776	.0476	.0515	1-1020	.0586	81.20
KIWI	2167.0	72/ 7	1.7760	1.737	2.303	49800	.348	.0782	.0482	.0521	1-1053	.0568	89.20
THRASHER	2312.0	76/19	1.9140	1.802	2.526	57300	.342	.0767	.0446	.0482	1-1202	.0595	86.70
JOREE	2515.0	76/19	2.0830	1.880	2.749	61700	.337	.0755	.0418	.0450	1-1202	.0621	86.70

HW#6

Figure 5.31

Three-phase 765-kV line for Example 5.10



Neutrals:
2—Alumoweld 7 no. 8
Radius = 0.489 cm
GMR = 0.0636 cm
Resistance = 1.52 Ω/km

Phase conductors:
4—ACSR 954 kcmil, 54/7
Radius = 1.519 cm
GMR = 1.229 cm
Resistance = 0.0701 Ω/km
Bundle spacing = 45.7 cm

Earth resistivity = 100 Ωm
Frequency = 60 Hz
Voltage = 765 kV

Table 5.6 Output data for Example 5.10

Series phase impedance matrix $\boldsymbol{Z_P}$ Eq. 5.7.19 Units:Ohms/km

$$\begin{bmatrix} 0.1181E+00+j5.532E-01 & 0.1009E+00+j2.340E-01 & 0.9813E-01+j1.842E-01 \\ 0.1009E+00+j2.339E-01 & 0.1200E+00+j5.500E-01 & 0.1009E+00+j2.339E-01 \\ 0.9813E-01+j1.842E-01 & 0.1009E+00+j2.340E-01 & 0.1181E+00+j5.532E-01 \end{bmatrix}$$

Series sequence impedance matrix $\boldsymbol{Z_S}$ Eq. 5.7.25 Units: Ohms/km

$$\begin{bmatrix} 0.3187E+00+j9.869E-01 & 0.1264E-00-j9.112E-03 & -.1421E-01-j6.389E-03 \\ -.1421E-01-j6.374E-03 & 0.1875E-01+j3.347E-01 & -.2903E-01+j1.814E-02 \\ 0.1262E-01-j9.117E-03 & 0.3022E-01+j1.607E-02 & 0.1875E-01+j3.347E-01 \end{bmatrix}$$

Shunt phase admittance matrix $\boldsymbol{Y_P}$ Eq. 5.11.16 Units: S/km

$$\begin{bmatrix} +j4.311E-06 & -j7.666E-07 & -j2.167E-07 \\ -j7.666E-07 & +j4.439E-06 & -j7.666E-07 \\ -j2.167E-07 & -j7.666E-07 & +j4.311E-06 \end{bmatrix}$$

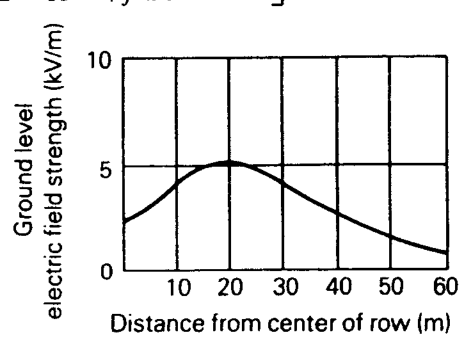
Shunt sequence admittance matrix $\boldsymbol{Y_S}$ Eq. 5.11. 19 Units: S/km

$$\begin{bmatrix} 0.0000E+00 \quad +j3.187E-06 & -.1219E-06 \quad +j7.036E-08 & 0.1219E-06 \quad +j7.036E-08 \\ 0.1219E-06 \quad +j7.036E-08 & -.3901E-13 \quad +j4.937E-06 & 0.3544E-06 \quad -j2.046E-07 \\ -.1219E-06 \quad +j7.036E-08 & -.3544E-06 \quad -j2.046E-07 & 0.3901E-13 \quad +j4.937E-06 \end{bmatrix}$$

Conductor surface electric field strength Eqs. 5.12.1–5.12.5

$E_{r\max} = 19.3\,\mathrm{kV_{rms}/cm}$

Lateral profile of ground-level electric field strength Eq. 5.12.6



HW#6

5.31 Rework Problem 5.30 with one neutral wire located 6 m directly above the center phase conductor. Compare the series sequence impedance matrix with that of Problem 5.30.

5.32 Using the LINE CONSTANTS program, compute the shunt sequence admittance matrix for the line in Problem 5.13. Assume an average line height of 20 m and no neutral wires. Compare the computed positive-sequence shunt admittance with the result calculated in Problem 5.21.

5.33 Rework Problem 5.32 with two neutral wires located 7 m above and 8 m to the left and right of the center bundle.

5.34 Using the LINE CONSTANTS program, compute the conductor surface electric field strength and the ground-level electric field strength profile for the line in Problem 5.33. Assume a 100 m right-of-way width.

5.35 Determine the effect of a 10% decrease as well as a 10% increase in phase spacing on the conductor surface electric field strength and on the ground-level electric field strength profile for the line in Problem 5.34.

5.36 Determine the effect of a 10% decrease as well as a 10% increase in the average line height on the conductor surface electric field strength as well as the ground-level electric field strength profile for the line in Problem 5.34.

5.37 Using the LINE CONSTANTS program, calculate the equivalent series sequence impedance matrix and the equivalent shunt sequence admittance matrix for the double-circuit, three-phase line shown in Figure 5.34 with phase arrangement I.

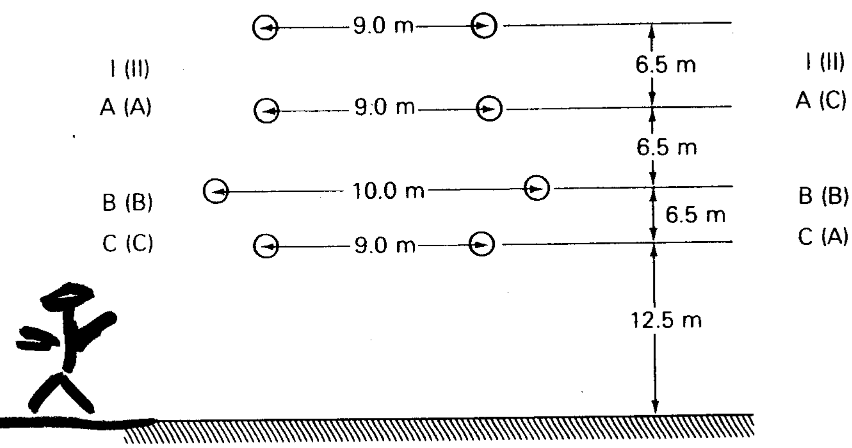
Figure 5.34

Double-circuit line for Problems 5.37 and 5.38

Phase conductors:
1—ACSR 2515 kcmil, 76/19
Radius = 2.388 cm
GMR = 1.893 cm
Resistance = 0.0280 Ω/km

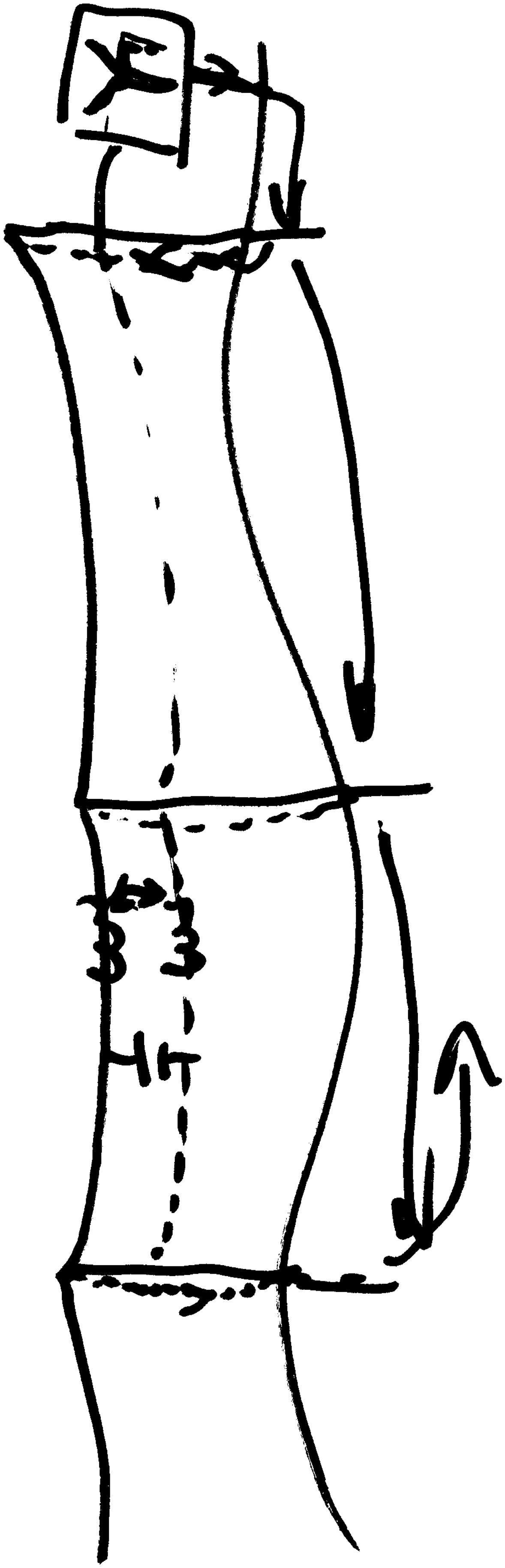
Neutrals:
2—Alumoweld 7 no. 8
Radius = 0.489 cm
GMR = 0.0636 cm
Resistance = 1.52 Ω/km

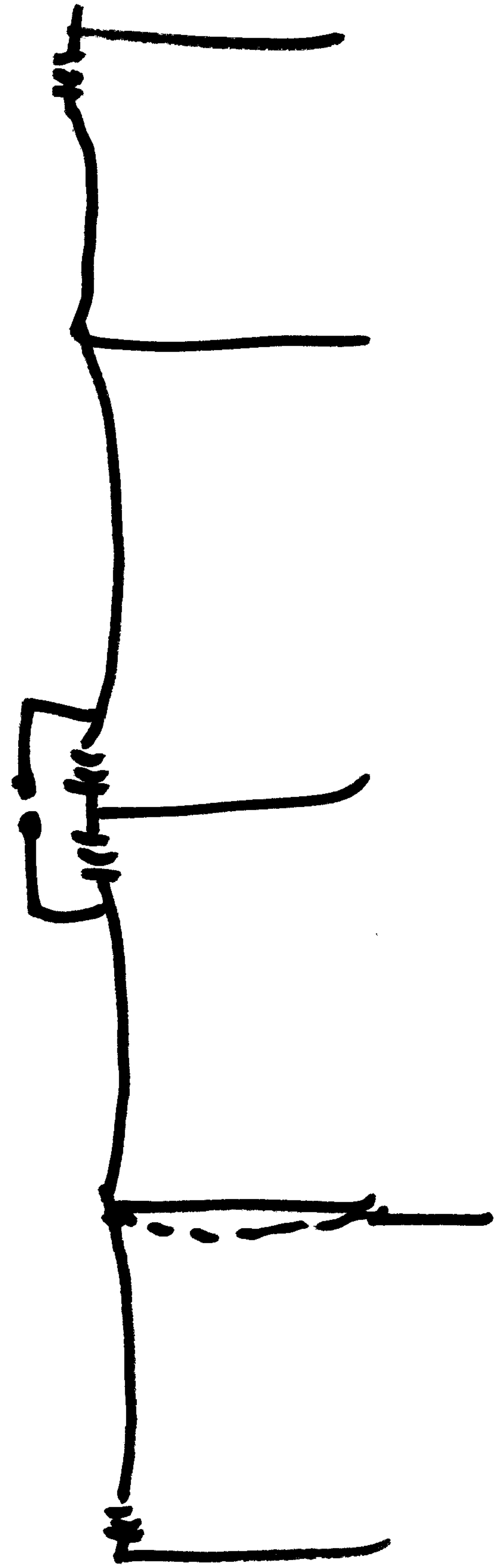
Earth resistivity = 100 Ωm
Frequency = 60 Hz
Voltage = 345 kV

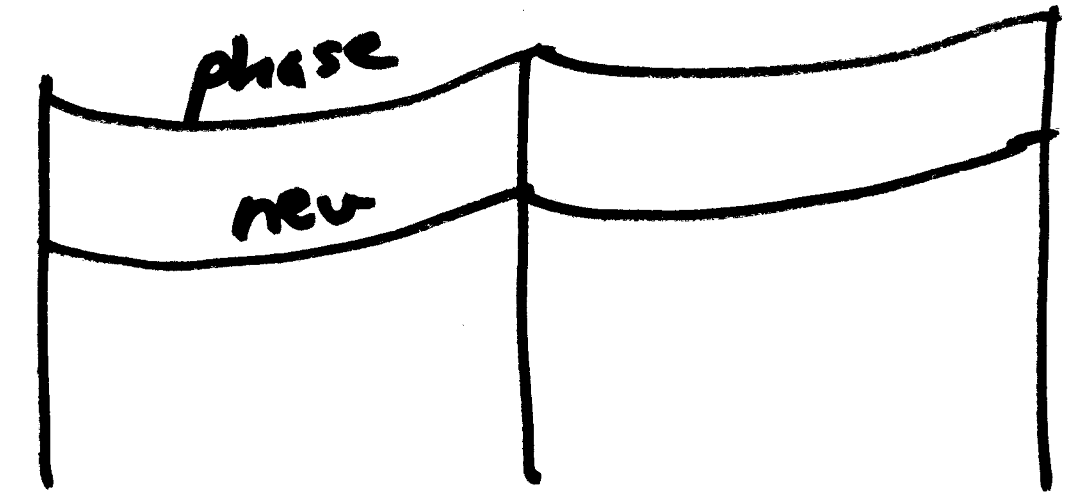


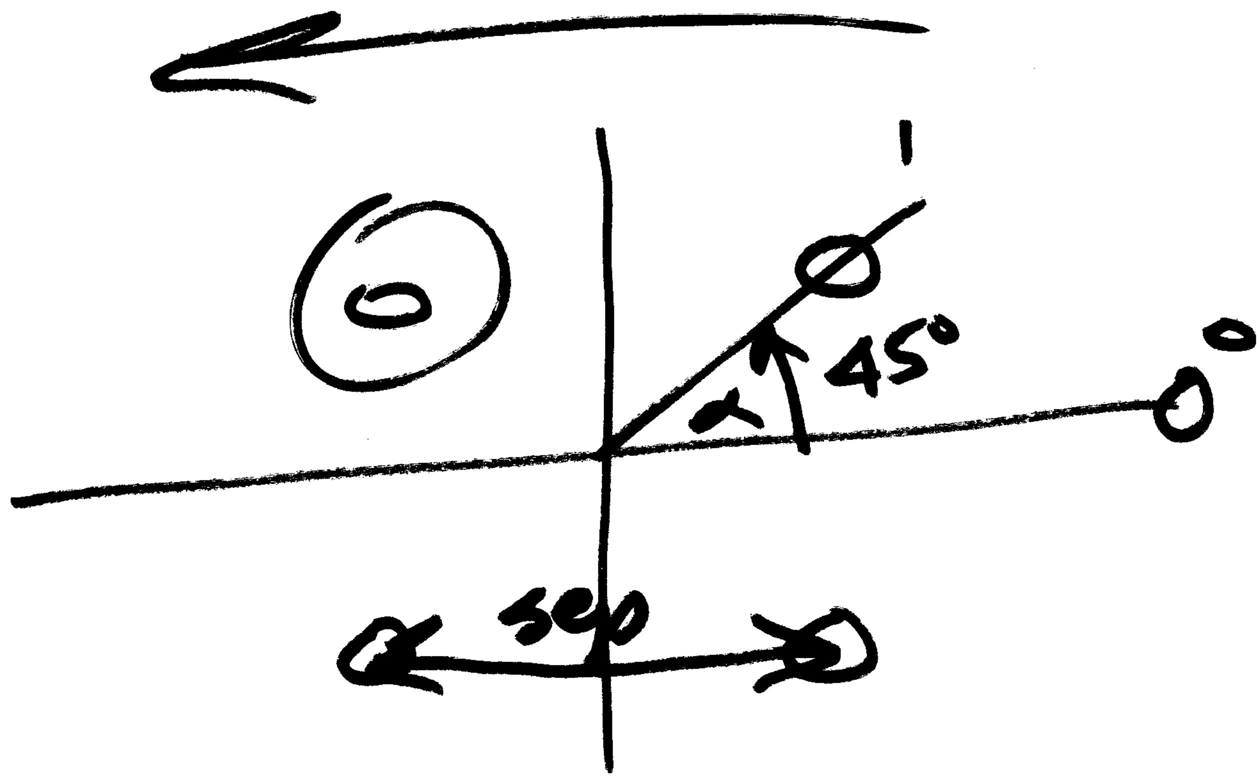
$\vec{E}, \vec{H}$

5.38 Rework Problem 5.37 for phase arrangement II shown in parentheses in Figure 5.34. Compare the computed results of the two phase arrangements.






phase
neu


α
45°
0°
sep

x.lis file:

in c:/atp/atpdraw/lcc/....*.lis

Use "line check" also....

Click on ATP → Linecheck