**EE 5240 - Lecture 5** Jan 23, 2019

**Topics for Today**:

- Questions from last lectures?
- Course Expectations
    - “3.5-for-one rule...” at least 10.5 hrs/wk !
    - Check web page, print out notes/info and read before coming to class, if available.
    - Comments on Homework #1
- Today -
    - “Vectors” can be row vector or column vector – pay attention when entering into MatLab.
    - Linked lists - “in situ” dynamic changes
    - System Data & Parameters:
        - Line Data
        - Generator Data
        - Transformer Data

**Vectors :**

Row Vectors

$$B = [1 \quad 2 \quad 3 \quad 4]$$

Column Vectors

$$B = [1;\ 2;\ 3;\ 4]$$

↑ MatLab: use semi-colons to divide rows!

$$\Longrightarrow \quad B = \begin{bmatrix} 1 \\ 2 \\ 3 \\ 4 \end{bmatrix}$$

## OPEN POSITIONS –

IOPEN: POINTER TO FIRST OPEN LOCATION AT BOTTOM OF LIST.

For open positions within List:

NOPEN = No. of "gaps" in list vector.

| | MOPEN |
|---|---|
| 1 | 10 |
| 2 | 7 |
| 3 | 12 |
| 4 | |

Ex: NOPEN = 3 use MOPEN (3)

If NOPEN = 0
Then go to

OBJECT: USE TOP OF STORAGE VECTOR.

Inverting $[A]$:

$$[A][x] = [B]$$
$$[A]^{-1}[A][x] = [A]^{-1}[B]$$

- Sparse $[Y_{Bus}]$ inverts to be a full $[Z_{Bus}]$.
- Extra storage
- Very inefficient: too many floating point operations.

Better; in situ

- Gauss Elim.
- Gauss-Jordan
- LU Factorization ← Mainstay Method.

Also called Triangularization

Print & study paper!

Example of "in situ" algorithm.

Gauss Elimination

FLOPS

$$[A][X] = [B]$$

$$\begin{bmatrix} 1 & 1 & 1 & -1 \\ 1 & -1 & -1 & 1 \\ 2 & 1 & -1 & 2 \\ 3 & 1 & 2 & -1 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \end{bmatrix} = \begin{bmatrix} 2 \\ 0 \\ 9 \\ 7 \end{bmatrix}$$

Soln. method: does row operations on [A] & [B] values in place. Avoids computation & storage overhead of inverting [A].

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$$\begin{array}{l} D1 \\ D2 \\ D3 = C3/(-2) \\ D4 = C4 - D3 \end{array} \left[\begin{array}{cccc|c} 1 & 1 & 1 & -1 & 2 \\ 0 & 1 & 1 & -1 & 1 \\ 0 & 0 & 1 & -3/2 & -3 \\ 0 & 0 & 0 & +3/2 & 6 \end{array}\right]$$

$$\left[\begin{array}{cccc|c} 1 & 1 & 1 & -1 & 2 \\ 0 & 1 & 1 & -1 & 1 \\ 0 & 0 & 1 & -3/2 & -3 \\ 0 & 0 & 0 & 1 & 4 \end{array}\right]$$

Gauss Elim. is Complete.

$\boxed{\text{Back Substitution}}$

$X_4 = 4$

$X_3 - \frac{3}{2}X_4 = -3$

$X_3 - \frac{3}{2}(4) = -3$

$X_3 = 3$

$X_2 + X_3 - X_4 = 1$

$X_2 + 3 - 4 = 1$

$X_2 = 2$

$X_1 = 1$

$$X = \begin{bmatrix} 1 \\ 2 \\ 3 \\ 4 \end{bmatrix}$$

# Back to Gauss Elimination

$$
\begin{array}{c}
\underline{\text{STEP Row}} \\
\text{A1} \\
\text{A2} \\
\text{A3} \\
\text{A4}
\end{array}
\quad
\left[\begin{array}{cccc:c}
1 & 1 & 1 & -1 & 2 \\
1 & -1 & -1 & 1 & 0 \\
2 & 1 & -1 & 2 & 9 \\
3 & 1 & 2 & -1 & 7
\end{array}\right]
$$

Normalize to row's main diagonal & eliminate column positions below main diagonal.

Solve for $x_4$ first, then <u>back substitute</u>.

$$\begin{array}{l} B1 = A1/1 \\ B2 = A2 - B1 \\ B3 = A3 - 2B1 \\ B4 = A4 - 3B1 \end{array} \left[\begin{array}{cccc|c} 1 & 1 & 1 & -1 & 2 \\ 0 & -2 & -2 & 2 & -2 \\ 0 & -1 & -3 & 4 & 5 \\ 0 & -2 & -1 & 2 & 1 \end{array}\right]$$

$$\begin{array}{l} C1 \\ C2 = B2/(-2) \\ C3 = B3 + C2 \\ C4 = B4 + 2C2 \end{array} \left[\begin{array}{cccc|c} 1 & 1 & 1 & -1 & 2 \\ 0 & 1 & 1 & -1 & 1 \\ 0 & 0 & -2 & 3 & 6 \\ 0 & 0 & 1 & 0 & 3 \end{array}\right]$$

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Gauss Jordan: Similar to Gauss, but also eliminates upper diagonal:

If Gauss-Jordan was used:

$$\left[\begin{array}{cccc|c} 1 & 0 & 0 & 0 & 1 \\ 0 & 1 & 0 & 0 & 2 \\ 0 & 0 & 1 & 0 & 3 \\ 0 & 0 & 0 & 1 & 4 \end{array}\right]$$

More calcs req'd in elimination but no back-substitution is required.

$\Rightarrow$ **LU Factorization is most practical.**

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# System Data & System Parameters

(GOAL: Build [$Y_{Bus}$] from system data.)

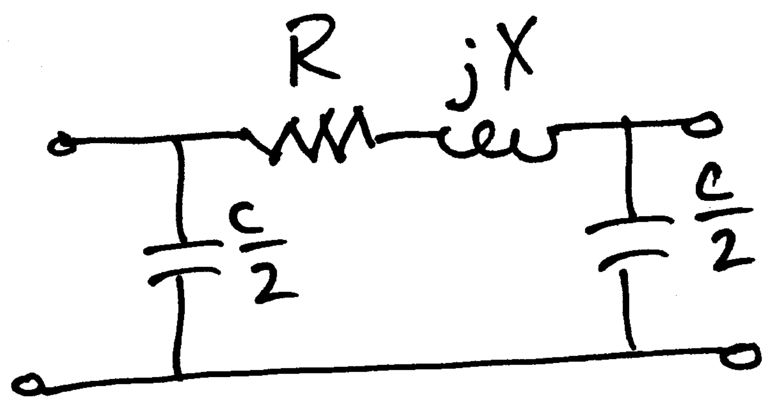
(See web page – Standard Data Cases
– Data File Formats
– CDF (**IEEE**)
– PTI
– **PEÇO** )

## Line Data:

Example from Stevenson:

| Line, bus to bus | Length km | Length mi | R Ω | X Ω | R per unit | X per unit | FULL [redacted] - LINE Charging Mvar† |
|---|---|---|---|---|---|---|---|
| 1–2 | 64.4 | 40 | 8 | 32 | 0.042 | 0.168 | 4.1 |
| 1–5 | 48.3 | 30 | 6 | 24 | 0.031 | 0.126 | 3.1 |
| 2–3 | 48.3 | 30 | 6 | 24 | 0.031 | 0.126 | 3.1 |
| 3–4 | 128.7 | 80 | 16 | 64 | 0.084 | 0.336 | 8.2 |
| 3–5 | 80.5 | 50 | 10 | 40 | 0.053 | 0.210 | 5.1 |
| 4–5 | 96.5 | 60 | 12 | 48 | 0.063 | 0.252 | 6.1 |

† At 138 kV.




C represents the "LINE CHARGING MVAR"

**HALF-LINE or FULL-LINE?**

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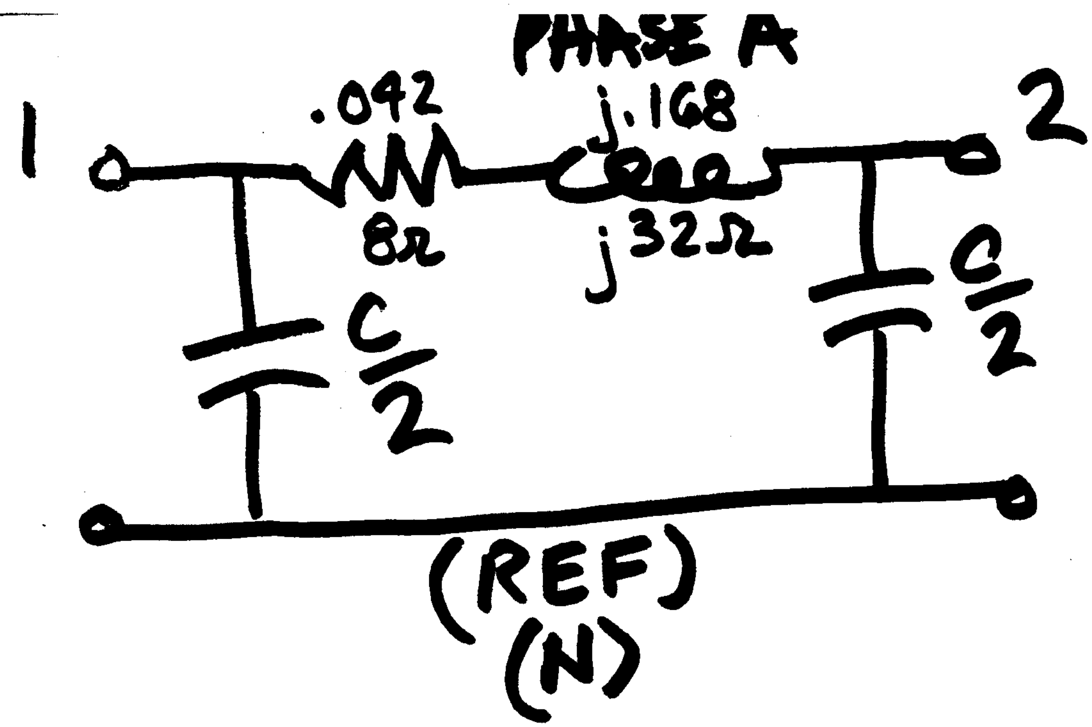



Recall:

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

$$\boxed{Z = 1/Y}$$

<u>Per Unit</u>

$$MVA_{3\phi\,BASE} = 100\ MVA$$

$$KV_{LL\,BASE} = 138\ KV$$

$$Z_{BASE} = \frac{138^2}{100} = 190\Omega$$

$$R_{pu} = \frac{8\Omega}{190\Omega} = .042\ p.u.$$

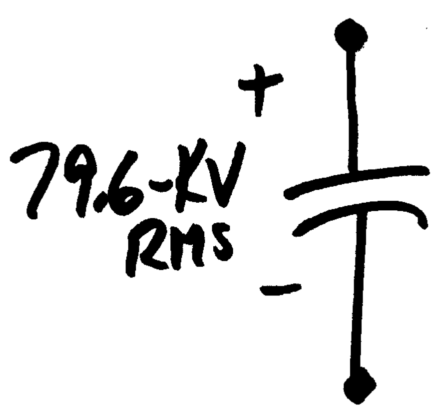
## Next: Susceptance ?

Full-Line Charging MVAR = 4.1 MVAR

Per Phase Equiv has 1/3 of total.

Each Cap $\left(\frac{C}{2}\right)$ is $\frac{4.1}{6} = 0.683$ MVAR

Rated L-N Voltage = $138/\sqrt{3} = 79.6$ KV




$$Q = \frac{V_{RMS}^2}{X_C}$$

$$X_C = \frac{V^2}{Q} = 9276\,\Omega$$


$$P = \frac{V_{RMS}^2}{R}$$

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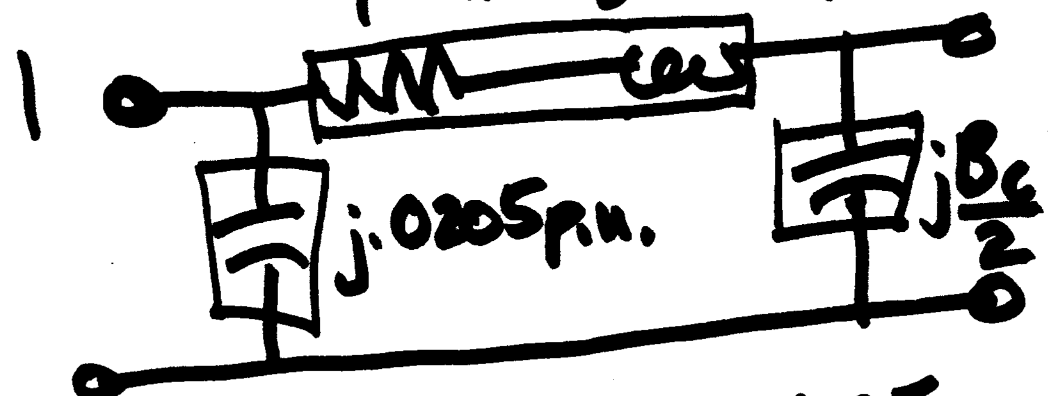
$-j\,9276\,\Omega = -j\,48.83\ \text{pu}$

$(-jX_c)$

<u>Goal:</u> Give $\pi$-EQUIV as $y$ values. $Y = \frac{1}{Z}$

$Y = 1.4 - j5.6$ p.u.




$j\frac{B_c}{2} = \frac{1}{jX_c} = j.0205\ \text{pu}$

At Bus 1: $y_{11} = 1.4 - j5.5795$ p.u.

$y_{12} = -1.4 + j5.6$ p.u. $= -\left[\frac{1}{R + jX}\right]$

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LINE CHARGING MVAR:

$\frac{B_c}{2} = .0205\,\text{p.u.}$ (HALF LINE CHARGING SUSCEPTANCE)

If $Q = \frac{V^2}{X} = V^2 B$

HALF-LINE CHG MVAR $= V^2 \frac{B_c}{2}$

$= (1.0\,\text{pu})^2 (.0205)$

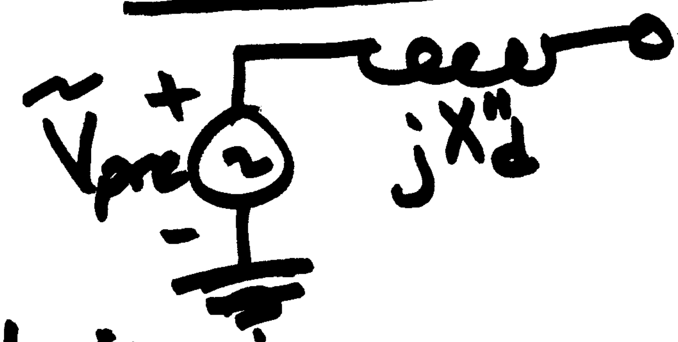
$= .0205\,\text{p.u.}$

$\times 100 = \boxed{2.05\,\text{MVAR}}$

KEY: $\frac{B_c}{2} = \frac{\text{(Full-Line) Per Unit Line Chg MVAR}}{MVA_{BASE} \times 2}$

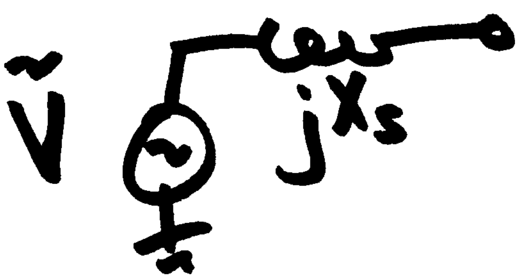
Generators:

S.C. Studies:

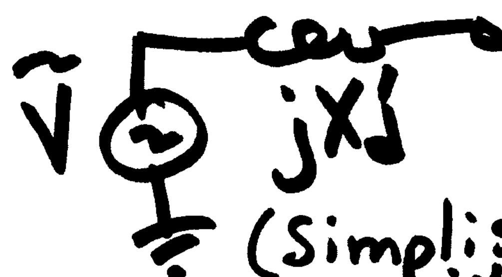



$\Rightarrow$ Norton

S-S. Phasor Analysis




Stability




(Simplistic)

$jX_d, jX_q$