Washington State University

EE 521/ECE 582 – Analysis of Power systems

Class #13 – October 6, 2022

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Reminders

- Student Hours This Week & Next
  - **Friday 1:30-2:30 pm** Zoom or EME 35 Pullman
  - **Tuesday 4:30-5:30 pm (after class)** – Zoom or EME 35 Pullman
  - **Wednesday 4-5 pm** Zoom or EME 35 Pullman
  - **Friday 1:30-2:30 pm** Zoom or EME 35 Pullman

  Additional Office Hours next week will be posted
- Remember the Discussion Set Assignment
  - 10/11 Discussions
- Final Paper – Think about Topic - Oct 14
- NAPS or WPRC Next week?

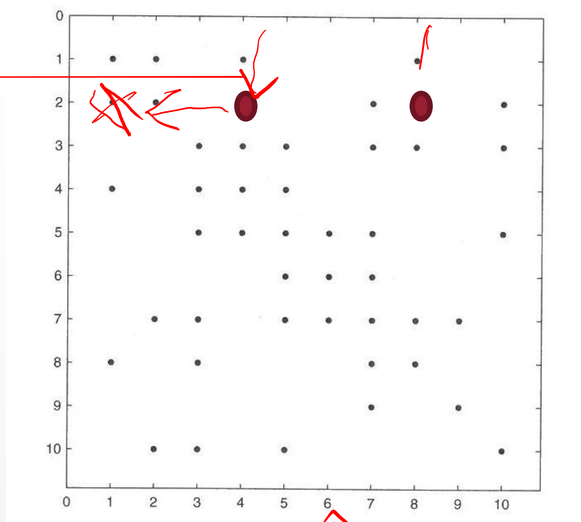
Program #2 – Sparse Matrices Program

- **Full Newton Raphson** -- Take the Jacobian Matrix from Program #1 (with taps) and solve the problem using Sparse Matrix Techniques
- **Fast Decoupled Power Flow** – Use Sparse Matrix Techniques for B' and B'' and solve. ~~Use Scheme 0 to solve Fast Decoupled Power Flow~~
- **Extra Credit** -- Fast Decoupled Power Flow – Use Sparse Matrix Techniques for B' and B'' and solve. Use Scheme 0 to solve Fast Decoupled Power Flow

NR NIC

**** Do not use the SEARCH function as that is not an acceptable method ****

Example of Adding a New Term/Fill



Row

2,4

2,8

15 → 36 → 34 → 23

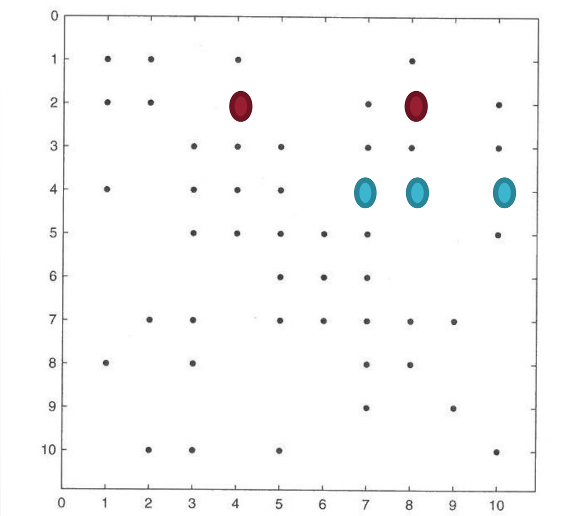
2,1   2,2   2,7

2,4   45   2,8   2,10

i	NROW	NCOL	NIR	NIC	Value
1	8	8	0	0	–28
2	7	2	35	17	5
3	10	5	41	0	7
4	5	10	0	41	7
5	5	7	4	25	3
6	6	6	25	42	–33
7	6	5	6	30	10
8	1	8	0	~~18~~ 46	8
9	5	5	28	7	–44
10	1	4	8	~~12~~ 45	19
11	4	3	27	40	6
12	8	3	44	14	1
13	3	4	29	27	6
14	10	3	3	0	9
15	2	1	36	20	2
16	9	7	43	0	13
17	10	2	14	0	10
18	3	8	19	26	1
19	3	10	0	4	9
20	4	1	11	22	19
21	7	7	26	44	–68
22	8	1	12	0	8
23	2	10	0	19	10
24	3	3	13	11	–40
25	6	7	0	21	19
26	7	8	38	1	15
27	4	4	39	31	–38
28	5	6	5	6	10
29	3	5	33	39	11
30	7	5	42	3	3
31	5	4	9	0	9
32	1	2	10	36	2
33	3	7	18	5	9
34	2	7	~~23~~ 46	33	5
35	7	3	30	12	9
36	2	2	~~34~~ 45	2	–21
37	1	1	32	15	–33
38	7	9	0	43	13
39	4	5	0	9	9
40	5	3	31	35	11
41	10	10	0	0	–30
42	7	6	21	0	19
43	9	9	0	0	–17
44	8	7	1	16	15
45	2	4	34	13	X
46	2	8	23	18	X

i	FIR	FIC
1	37	37
2	15	32
3	24	24
4	20	10
5	40	29
6	7	28
7	2	34
8	22	8
9	16	38
10	17	23

Example of Adding a New Term/Fill



i	NROW	NCOL	NIR	NIC	Value
1	8	8	0	0	–28
2	7	2	35	17	5
3	10	5	41	0	7
4	5	10	0	41	7
5	5	7	4	25	3
6	6	6	25	42	–33
7	6	5	6	30	10
8	1	8	0	~~18~~ 46	8
9	5	5	28	7	–44
10	1	4	8	~~13~~ 45	19
11	4	3	27	40	6
12	8	3	44	14	1
13	3	4	29	27	6
14	10	3	3	0	9
15	2	1	36	20	2
16	9	7	43	0	13
17	10	2	14	0	10
18	3	8	19	~~26~~ 48	1
19	3	10	0	~~4~~ 49	9
20	4	1	11	22	19
21	7	7	26	44	–68
22	8	1	12	0	8
23	2	10	0	19	10
24	3	3	13	11	–40
25	6	7	0	21	19
26	7	8	38	1	15
27	4	4	39	31	–38
28	5	6	5	6	10
29	3	5	33	39	11
30	7	5	42	3	3
31	5	4	9	0	9
32	1	2	10	36	2
33	3	7	~~10~~ 47	5	9
34	2	7	~~23~~ 46	33	5
35	7	3	30	12	9
36	2	2	~~34~~ 45	2	–21
37	1	1	32	15	–33
38	7	9	0	43	13
39	4	5	~~0~~ 47	9	9
40	5	3	31	35	11
41	10	10	0	0	–30
42	7	6	21	0	19
43	9	9	0	0	–17
44	8	7	1	16	15
45	2	4	34	13	X
46	2	8	23	18	X
47	4	7	48	~~[illegible]~~	X 5
48	4	8	49	26	X
49	4	10	0	4	X

i	FIR	FIC
1	37	37
2	15	32
3	24	24
4	20	10
5	40	29
6	7	28
7	2	34
8	22	8
9	16	38
10	17	23

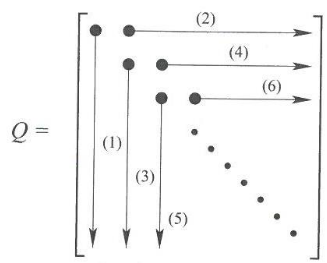


FIGURE 2.1
Order of calculating columns and rows of Q

A

known as *Crout's* algorithm for finding the LU factors [8]. Let the matrix Q be defined as

$$\boxed{Q \triangleq L + U - I} = \begin{bmatrix} l_{11} & u_{12} & u_{13} & \cdots & u_{1n} \\ l_{21} & l_{22} & u_{23} & \cdots & u_{2n} \\ l_{31} & l_{32} & l_{33} & \cdots & u_{3n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ l_{n1} & l_{n2} & l_{n3} & \cdots & l_{nn} \end{bmatrix} \qquad (2.24)$$

Crout's algorithm computes the elements of Q first by column and then row, as shown in Figure 2.1. Each element q_{ij} of Q depends only on the a_{ij} entry of A and previously computed values of Q.

Crout's Algorithm for Computing LU from A

1. Initialize Q to the zero matrix. Let $j = 1$.
2. Complete the jth column of Q (jth column of L) as

col

$$q_{kj} = a_{kj} - \sum_{i=1}^{j-1} q_{ki} q_{ij} \quad \text{for } k = j, \ldots, n \qquad (2.25)$$

1

3. If $j = n$, then stop.
4. Assuming that $q_{jj} \neq 0$, complete the jth row of Q (jth row of U) as

row

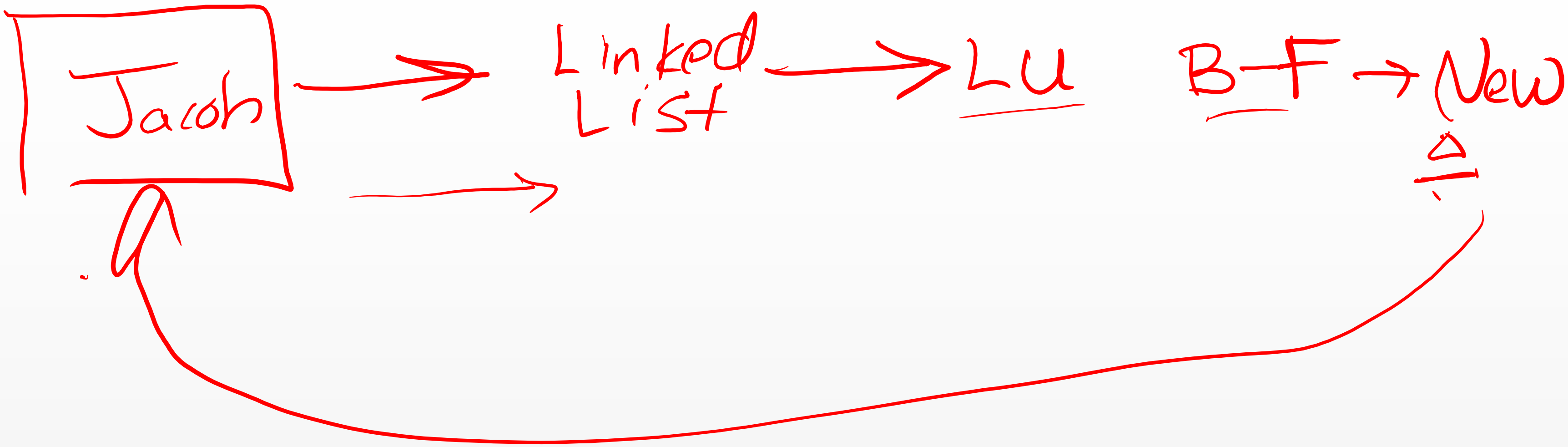
$$q_{jk} = \frac{1}{q_{jj}} \left(a_{jk} - \sum_{i=1}^{j-1} q_{ji} q_{ik} \right) \quad \text{for } k = j+1, \ldots, n \qquad (2.26)$$

2

5. Set $j = j + 1$. Go to step 2.

$$\begin{bmatrix} 1 & 3 & 4 \\ 2 & 1 & 2 \\ 4 & 3 & 5 \end{bmatrix} \qquad \text{FIR} \begin{bmatrix} 1 \\ 4 \\ 7 \end{bmatrix} \qquad \text{FIC} \begin{bmatrix} 1 \\ 2 \\ 3 \end{bmatrix}$$

#	ROW	COL	NIR	NIC	#
1	1	1	2	4	1
2	1	2	3	5	3
3	1	3	0	6	4
4	2	1	5	7	2
5	2	2	6	8	1
6	2	3	0	9	2
7	3	1	8	0	4
8	3	2	9	0	2
9	3	3	0	0	5


Jacob
Linked List
LU
B-F
New

$j = 1$

$\boxed{q_{11} = \boxed{a_{11}}}$

$q_{21} = a_{21}$

$q_{31} = a_{31}$

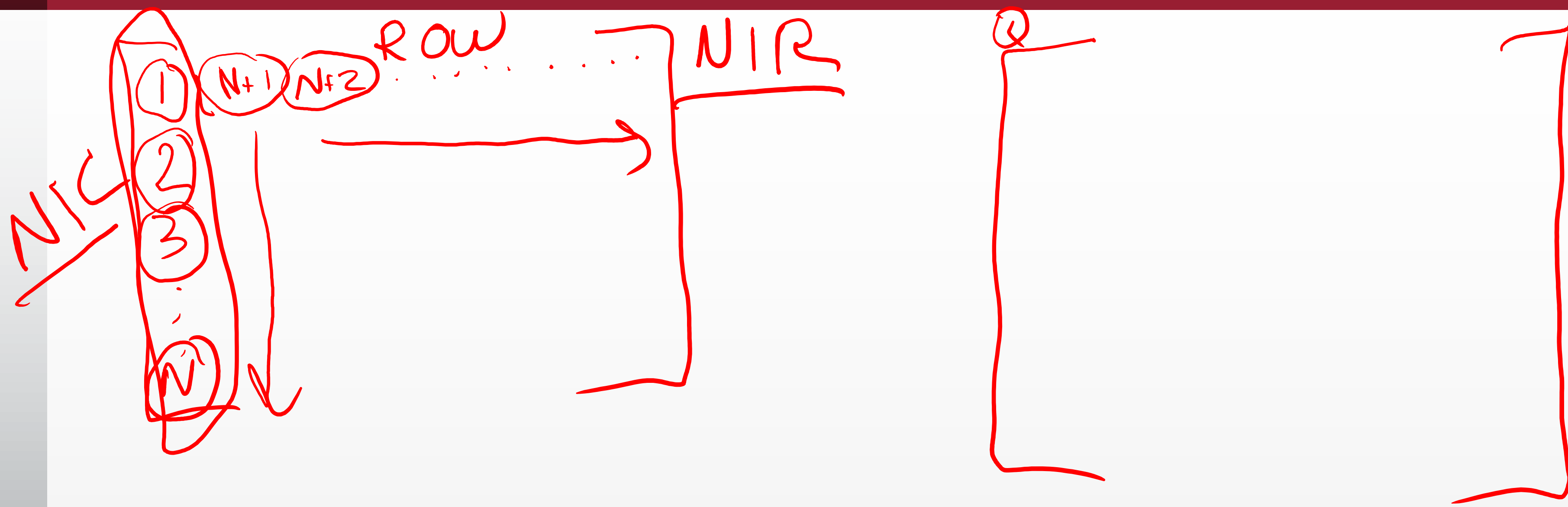
NIC

$q_{k1} = a_{k1} - \cancel{\sum q_{ki} \cdot q_{i1}}$

$q(row, 1) = \boxed{a(row, 1)}$

Row Col NIR NIC #

1
2
3
4
5
6
7
8
9


ROW
NIR
NIC
1
2
3
N
N+1
N+2
Q

col $\quad g_{kj} = a_{kj} - \sum_{i=1}^{j-1} g_{ki}\, g_{ij} \quad k = j \text{ to } N$

row $\quad g_{jk} = \frac{1}{g_{jj}} \left(a_{jk} - \sum_{i=1}^{j-1} g_{ji}\, g_{ik} \right) \quad k = j+1 \text{ to } N$

FIR $\longrightarrow$ FIC

$j=1$

$g_{11} = a_{11}$ NIC

$g_{21} = a_{21}$ NIC

$g_{31} = a_{31}$

$g_{12} = \dfrac{a_{12}}{g_{11}}$ NIR

$g_{13} = \dfrac{a_{13}}{g_{11}}$ NIR

$g(1,1) = a(1,1)$

$g_{22} = \boxed{a_{22}} - g_{21}\boxed{g_{12}}$

$g_{32} = \boxed{a_{32}} - g_{31}g_{12}$

$g_{23} = \dfrac{1}{g_{22}}\left(a_{23} - g_{21}g_{13}\right)$

$j=3$

$g_{33} = a_{33} - \left(g_{31}g_{13} + g_{32}g_{23}\right)$

A

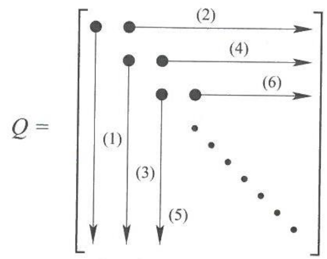
Element Row Col NIR NIC $\neq$

Q 11 — #A11

FIR FIC

FIR FIC

$$\begin{bmatrix} 1 & 2 & 3 \\ 4 & 5 & 6 \\ 7 & 8 & 9 \end{bmatrix} \times \begin{bmatrix} 0 & 3 & 5 \\ 1 & 6 & 7 \\ 3 & 8 & 2 \end{bmatrix} = \boxed{\quad}$$



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3. If $j = n$, then stop.
4. Assuming that $q_{jj} \neq 0$, complete the jth row of Q (jth row of U) as

$$q_{jk} = \frac{1}{q_{jj}} \left(a_{jk} - \sum_{i=1}^{j-1} q_{ji} q_{ik} \right) \quad \text{for } k = j+1, \ldots, n \tag{2.26}$$

5. Set $j = j + 1$. Go to step 2.

0,001

<

Sparse

0

$a_{kj} = 0$

$A \begin{bmatrix} \; \end{bmatrix}$

Q

~~col row~~

q_{11} 1 row col mk nic#

q_{1N}

q_{12}

Announcements

- Finish Chapter 4
- Review Sections 3.5.5 & 3.5.6
- Papers for Discussion Set #1 –Questions – Today and Responses by 10/11
- Work on Program #1
- Set up Time for Program #1 Discussions