Topics for Today:

- Announcements
  - Your Term Project is a PROJECT (not a summary paper), so be sure there is some application/implementation of the concepts and theory.
  - Software: online students - apply for ATP/ATPDraw license, verify licensing when you receive it by e-mail, and we will mail you the install CD.
  - ASPEN software - run off of MTU server via internet, see e-mail instructions.
  - Office: EERC 614. Phone: 906.487.2857
  - Recommended problems & all solutions: Ch.9, 13 solns now posted.

- Chapter 9 - Load Flow wrapup
  - Implementation of Loadflow for Slack, Gen, and Load Bus
  - Input/translation/conversion of system data.
  - Aspen
  - Corrective Actions for low or high bus voltage
  - Line Loading concerns
  - Contingencies
  - System Security - Operation, Protection, Cyber-security

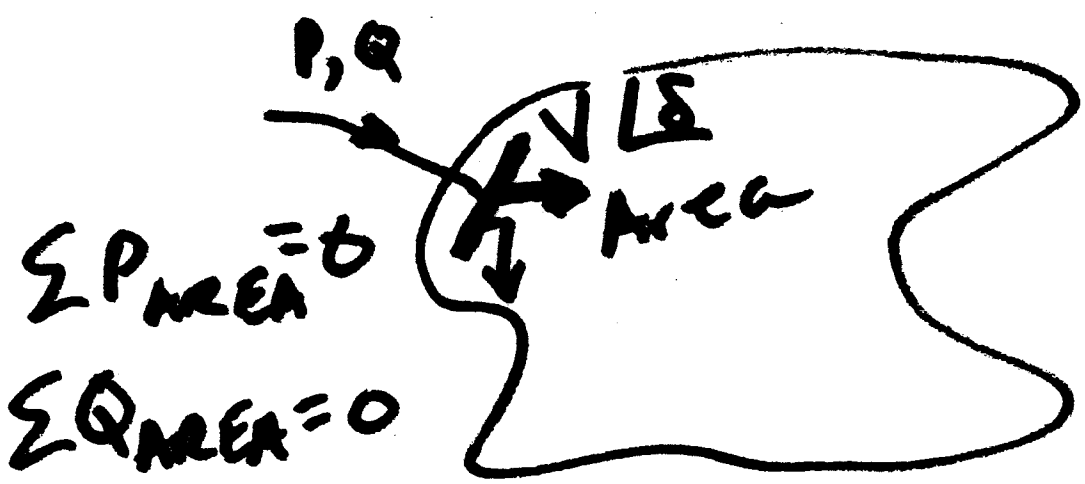
- Bus Types, DATA (Also: Loads, and Shunt devices)
- Lines
- Transformers
- Generators

PV — "Scheduled" P, Q

PQ — P, Q

or: [V-dependent P, Q]

SLACK / SWING / V-δ bus



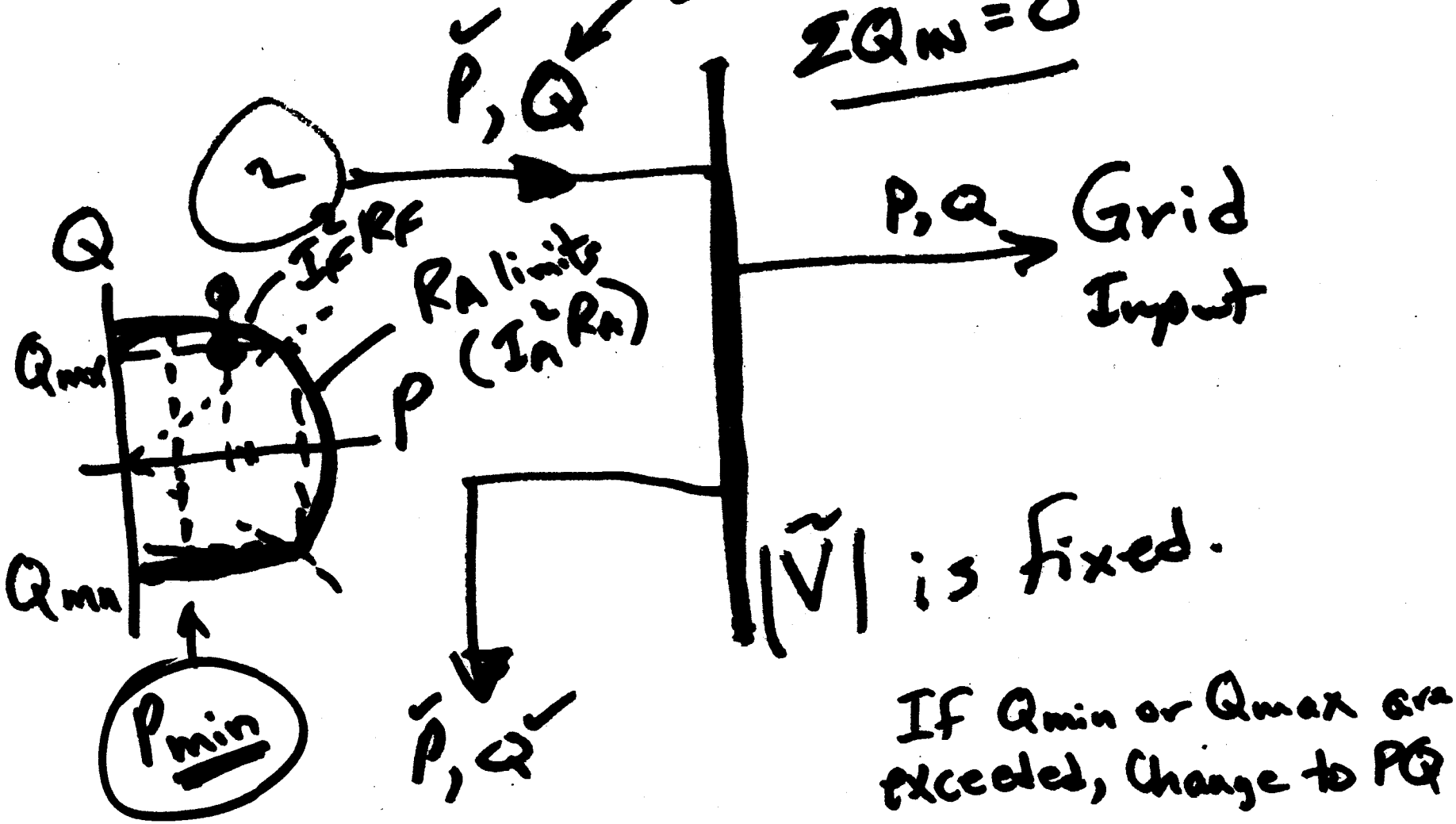
P, Q are "slack" variables.

Gen Bus (P-V Bus)

Solve for 2 Q & δ.
↑ solved

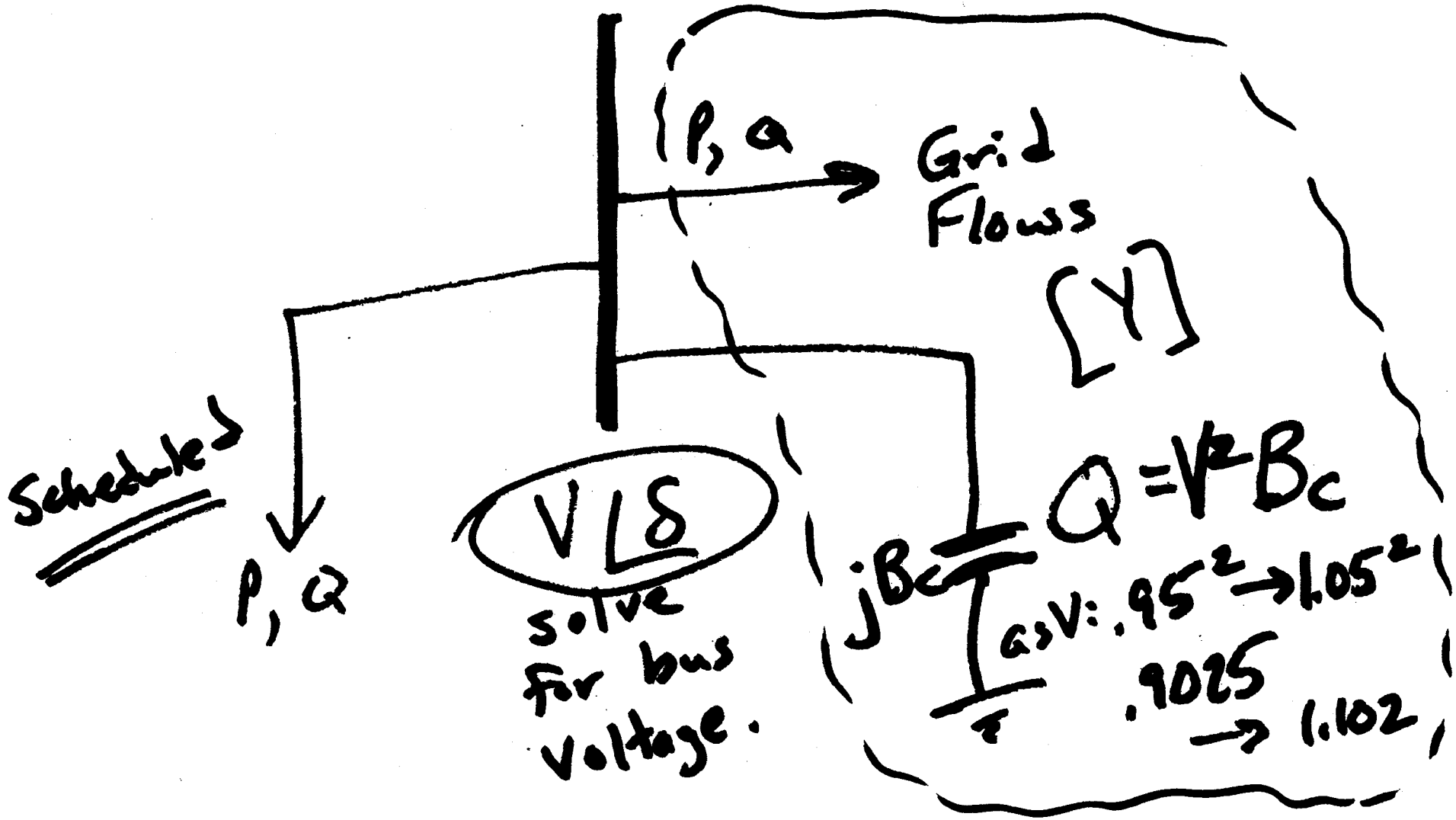
"Slack Variable"

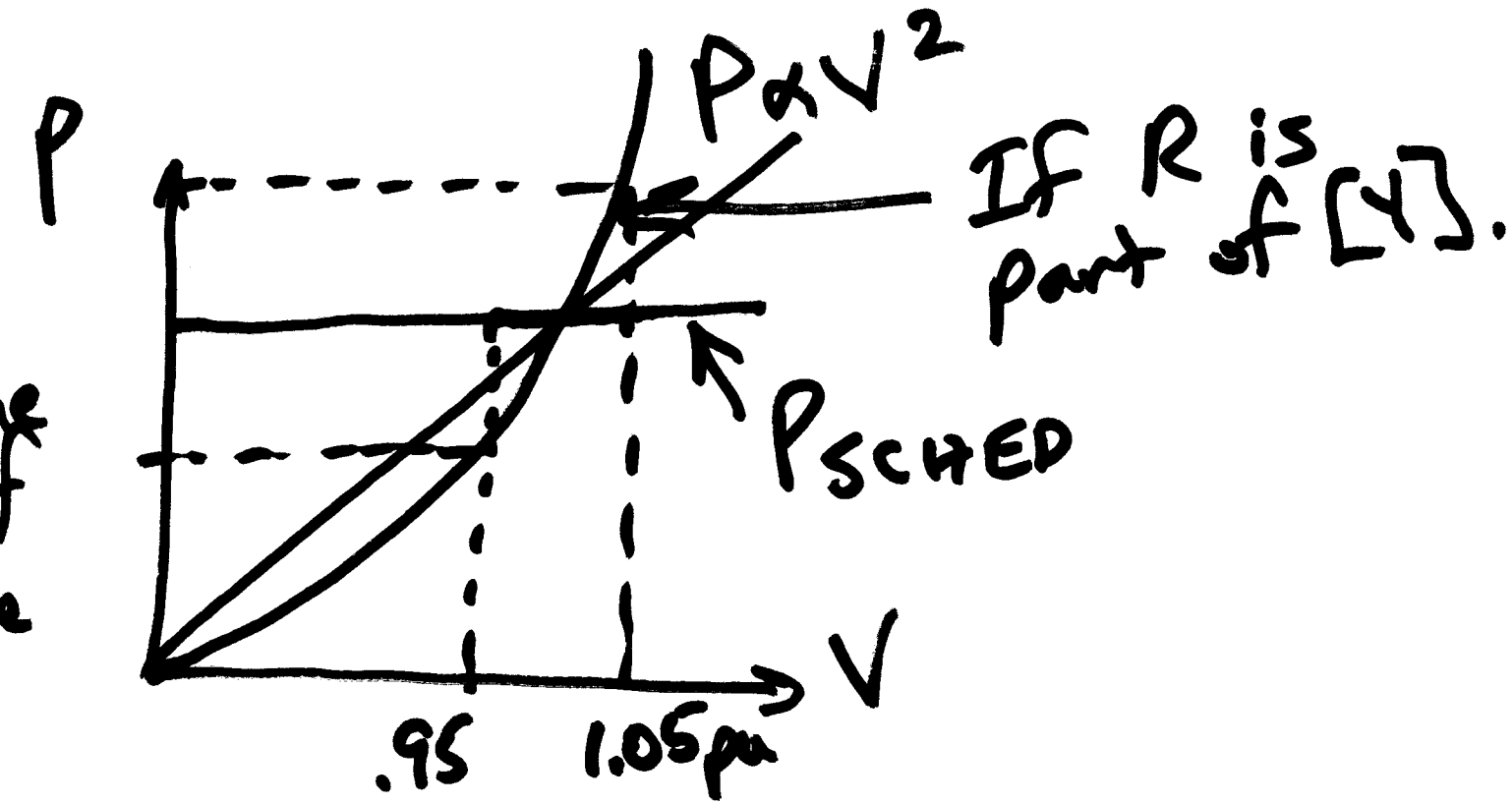
$\Sigma Q_{NN} = 0$



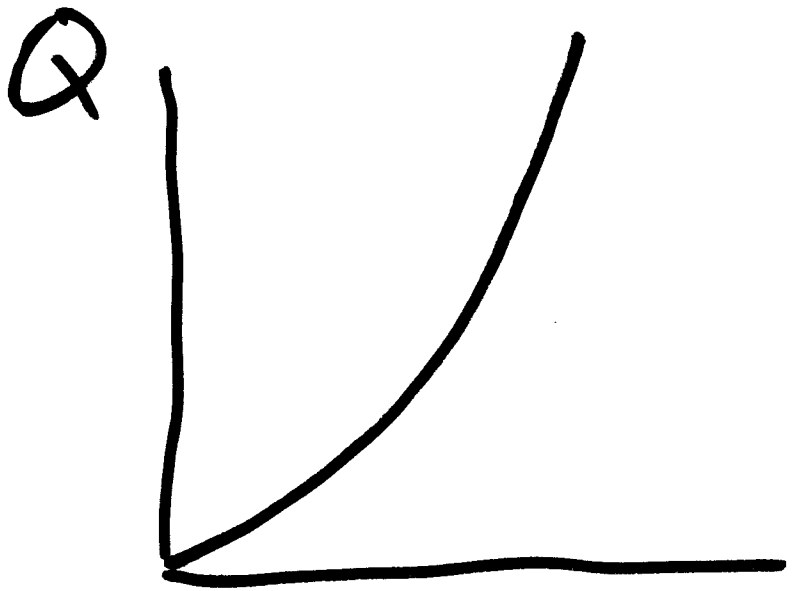
If Qmin or Qmax are exceeded, Change to PQ

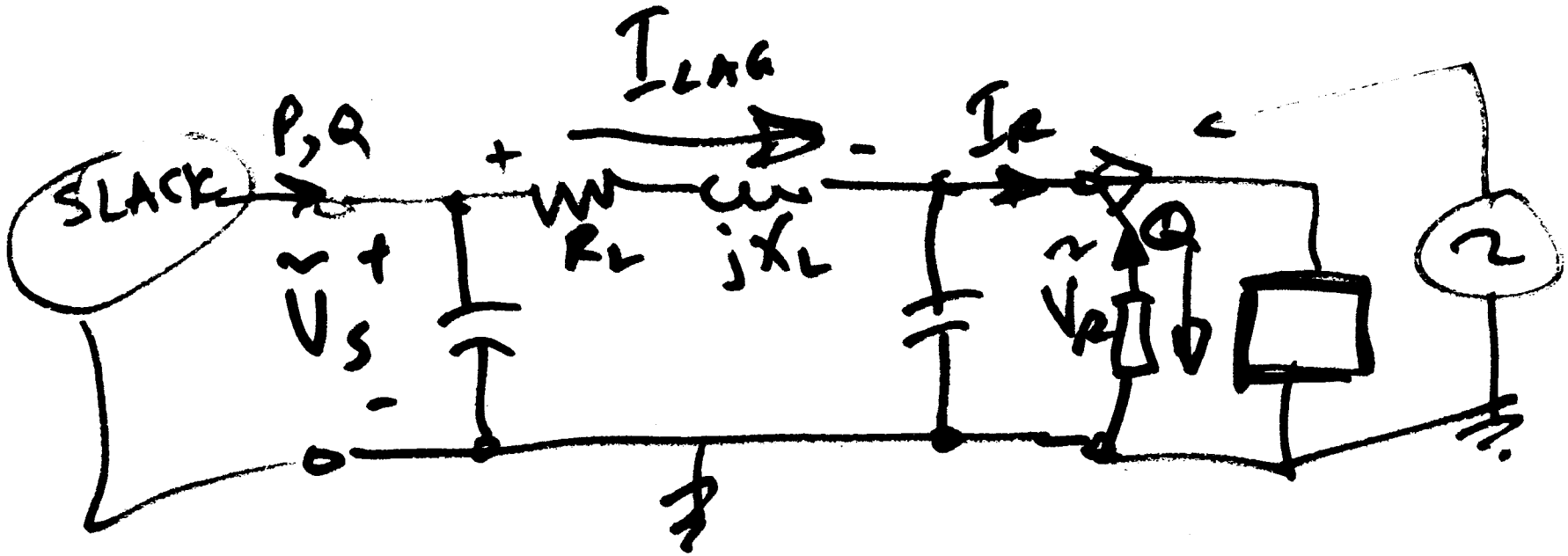
P-Q or Load Buses: Solve for $|\bar{V}|$ and δ

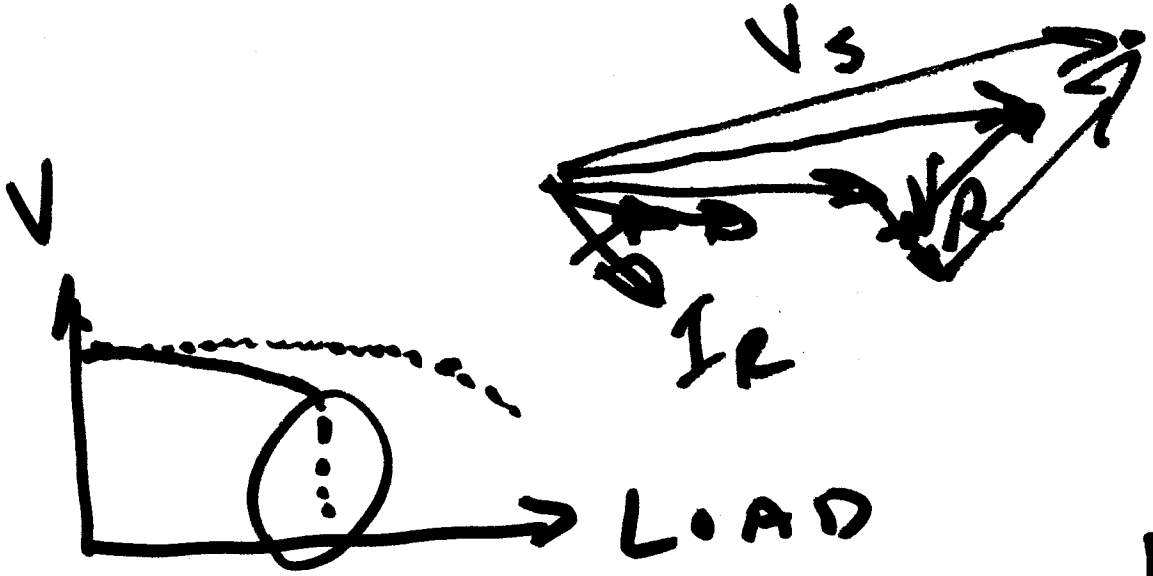




What is the nature of the aggregate Load?







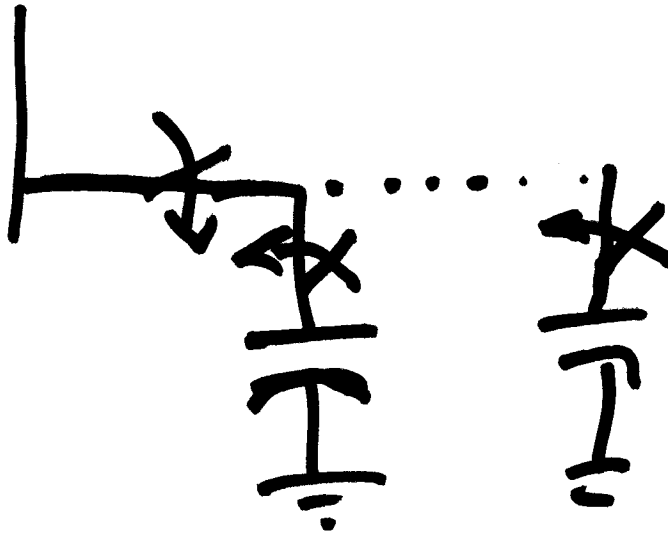
Voltage Collapse

"Var Reserve is depleted.

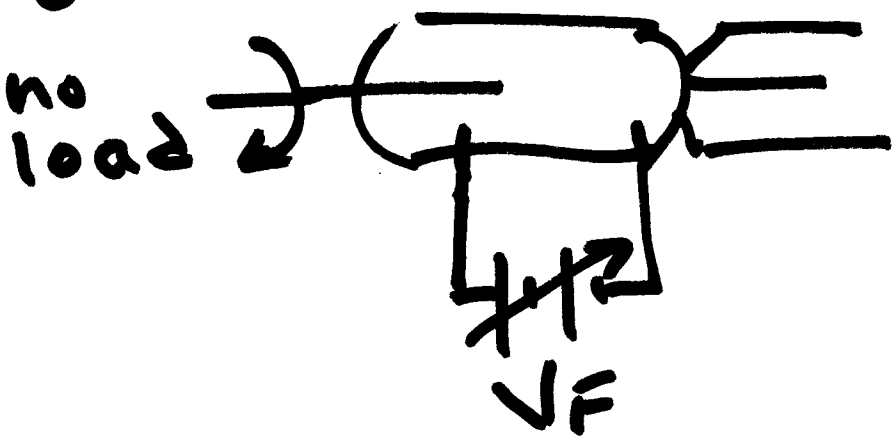
Control/Dynamic Var Support

VAR Sources

1) SLOW
   - CAP Bank on/off



2) Synchronous Condensor



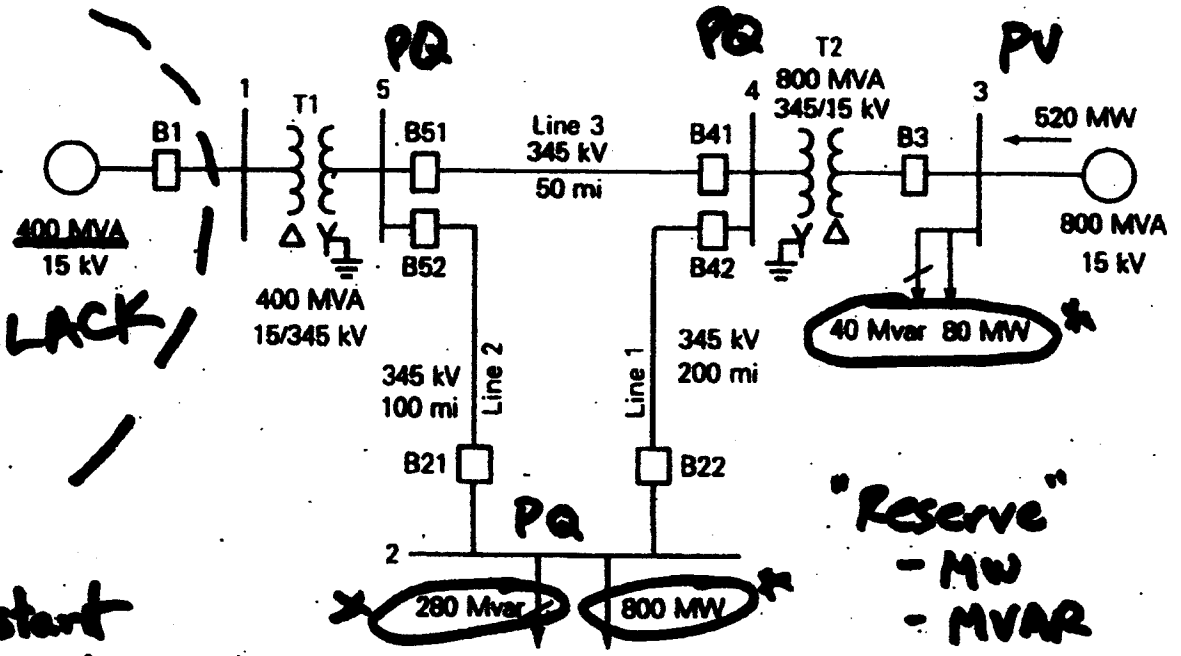
Continuous Controlled range of Vars.

3) Fast - FACTS - rapid control of Q
   SVC

Figure 6.2 shows a single-line diagram of a five-bus power system. Input data are given in Tables 6.1, 6.2, and 6.3. As shown in Table 6.1, bus 1, to which a generator is connected, is the swing bus. Bus 3, to which a generator and a load are connected, is a voltage-controlled bus. Buses 2, 4, and 5 are load buses. Note that the loads at buses 2 and 3 are inductive since $Q_2 = -Q_{L2} = -0.7$ and $-Q_{L3} = -0.1$ are negative.

For each bus k, determine which of the variables V_k, δ_k, P_k, and Q_k are input data and which are unknowns. Also, compute the elements of the second row of Y_{bus}.

Careful: GIGO



SLACK

* Assumed constant P,Q, i.e. don't change w/ bus voltage.

"Reserve"
- MW
- MVAR

p. 113 - Gen Capability

TABLE 6.1
Bus input data for Example 6.9*

Bus	Type	V per unit	δ degrees	P_G per unit	Q_G per unit	P_L per unit	Q_L per unit	$Q_{G_{max}}$ per unit	$Q_{G_{min}}$ per unit
1	Swing	1.0	0	—	—	0	0	—	—
2	Load	—	—	0	0	8.0	2.8		
3	Constant voltage	1.05	—	5.2	—	0.8	0.4	4.0	−2.8
4	Load	—	—	0	0	0	0	—	—
5	Load	—	—	0	0	0	0	—	—

*S_{base} = 100 MVA, V_{base} = 15 kV at buses 1, 3, and 345 kV at buses 2, 4, 5

TABLE 6.2
Line input data for Example 6.9

Bus-to-Bus	R′ per unit	X′ per unit	G′ per unit	B′ per unit	Maximum MVA per unit
2–4	0.0090	0.100	0	1.72	12.0
2–5	0.0045	0.050	0	0.88	12.0
4–5	0.00225	0.025	0	0.44	12.0

TABLE 6.3
Transformer input data for Example 6.9

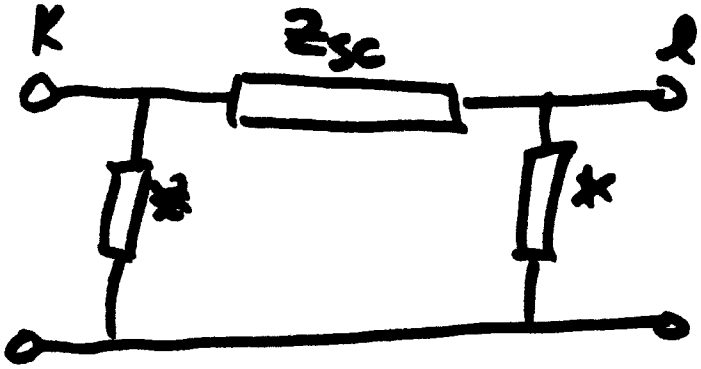
Bus-to-Bus	R per unit	X per unit	G_c per unit	B_m per unit	Maximum MVA per unit	Maximum TAP Setting per unit
1–5	0.00150	0.02	0	0	6.0	—
3–4	0.00075	0.01	0	0	10.0	—

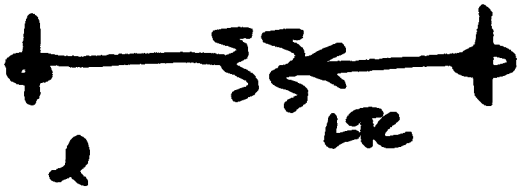
SOLUTION The input data and unknowns are listed in Table 6.4. For bus 1, the swing bus, P_1 and Q_1 are unknowns. For bus 3, a voltage-controlled bus, Q_3 and δ_3 are unknowns. For buses 2, 4, and 5, load buses, V_2, V_4, V_5 and δ_2, δ_4, δ_5 are unknowns.

TABLE 6.4
Input data and unknowns for Example 6.9

Bus	Input Data	Unknowns
1	$V_1 = 1.0, \delta_1 = 0$	P_1, Q_1
2	$P_2 = P_{G2} - P_{L2} = -8$ $Q_2 = Q_{G2} - Q_{L2} = -2.8$	V_2, δ_2
3	$V_3 = 1.05$ $P_3 = P_{G3} - P_{L3} = 4.4$	Q_3, δ_3
4	$P_4 = 0, Q_4 = 0$	V_4, δ_4
5	$P_5 = 0, Q_5 = 0$	V_5, δ_5

Transformers



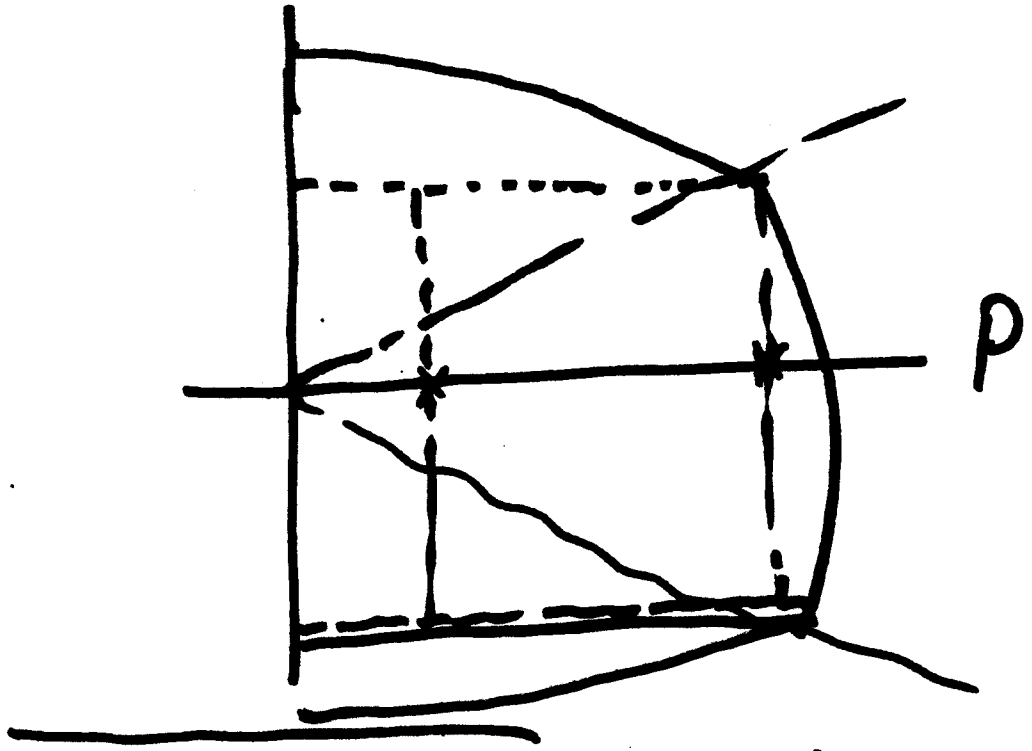


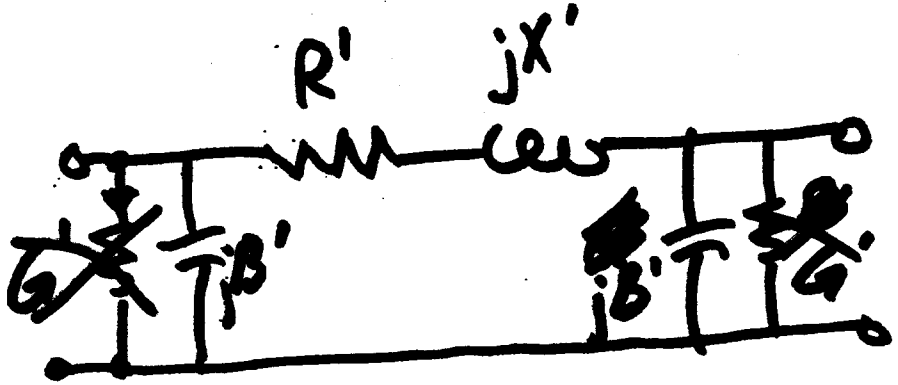
$$\begin{array}{c} \\ K \\ l \end{array} \begin{array}{c} \begin{array}{cc} K & l \end{array} \\ \begin{bmatrix} x & x \\ x & x \end{bmatrix} \end{array}$$

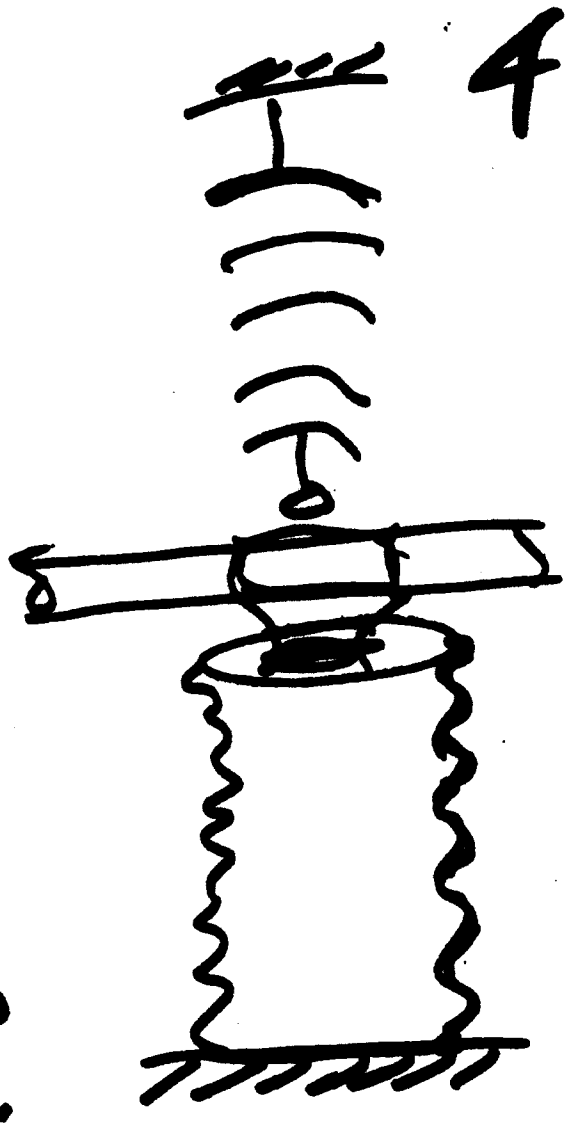
*Zero unless LTC or PS. tap ratio ≠ 1.

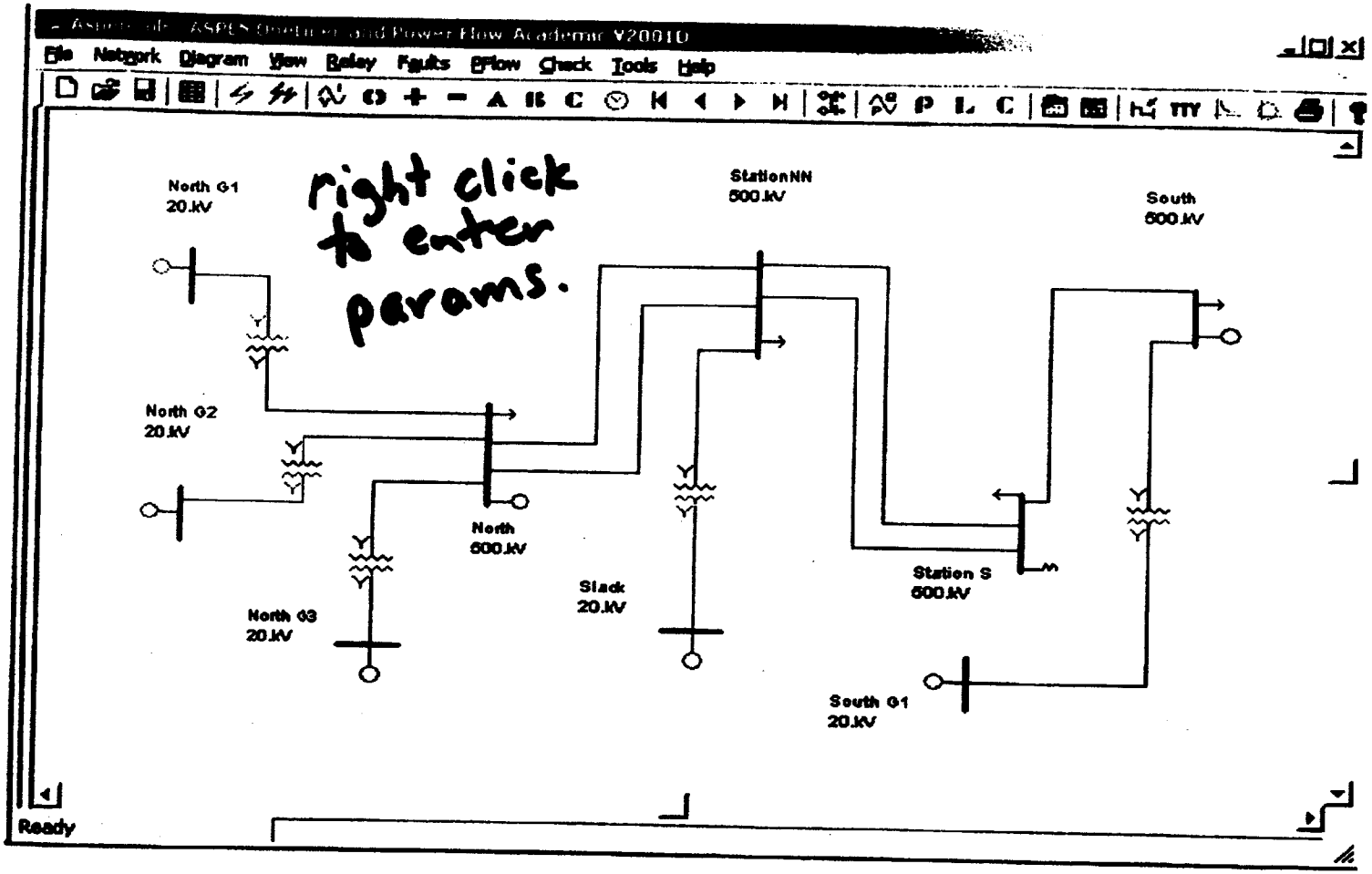
All effect into [Y].

Gen Var Limits



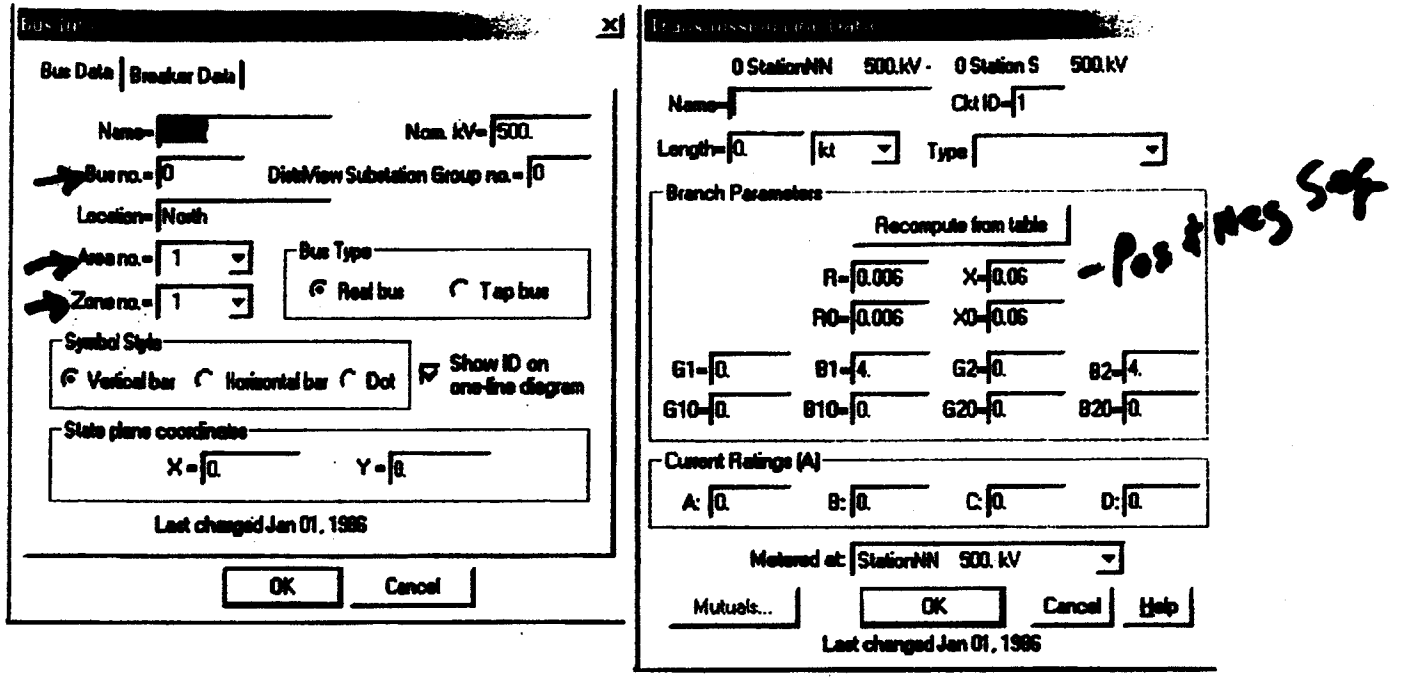






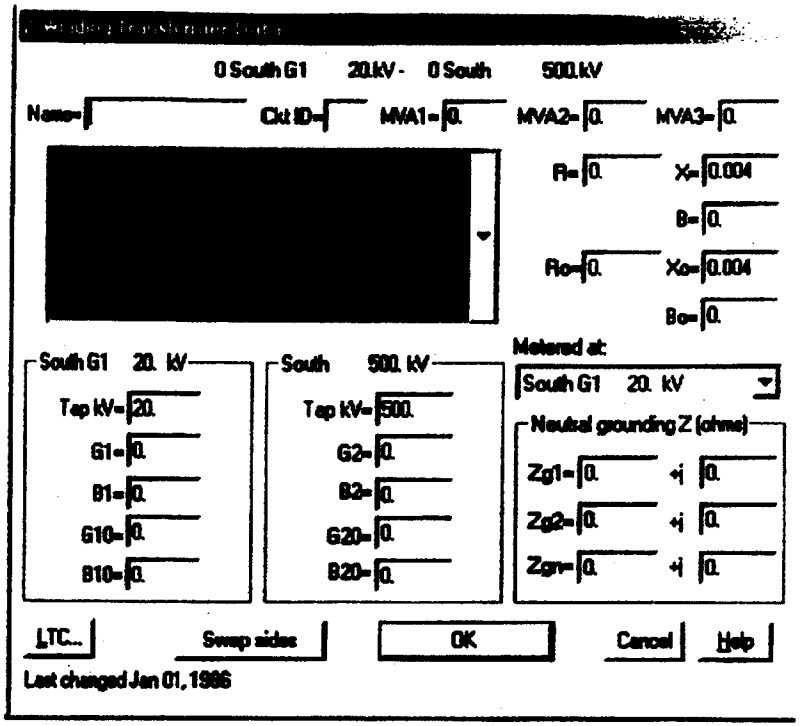
Alt - PrtScr → active window
Ctl - PrtScr → whole screen

] Paste into document.


Bus Data
Breaker Data
Name=
Nom. kV=500.
Bus no.=0
DistaView Substation Group no.=0
Location=North
Area no.=1
Zone no.=1
Bus Type
Real bus
Tap bus
Symbol Style
Vertical bar
Horizontal bar
Dot
Show ID on one-line diagram
State plane coordinates
X=0.
Y=0.
Last changed Jan 01, 1996
OK
Cancel
0 StationNN 500.kV - 0 Station S 500.kV
Name=
Ckt ID=1
Length=0.
kt
Type
Branch Parameters
Recompute from table
R=0.006
X=0.06
R0=0.006
X0=0.06
G1=0.
B1=4.
G2=0.
B2=4.
G10=0.
B10=0.
G20=0.
B20=0.
Current Ratings (A)
A: 0.
B: 0.
C: 0.
D: 0.
Metered at: StationNN 500. kV
Mutuals...
OK
Cancel
Help
Last changed Jan 01, 1996

6

- Pos & Neg Seq


0 South G1 20.kV - 0 South 500.kV
Name=
Ckt ID=
MVA1=0.
MVA2=0.
MVA3=0.
R=0.
X=0.004
B=0.
Ro=0.
Xo=0.004
Bo=0.
South G1 20. kV
Tap kV=20.
G1=0.
B1=0.
G10=0.
B10=0.
South 500. kV
Tap kV=500.
G2=0.
B2=0.
G20=0.
B20=0.
Metered at:
South G1 20. kV
Neutral grounding Z (ohms)
Zg1=0. +j 0.
Zg2=0. +j 0.
Zgn=0. +j 0.
LTC...
Swap sides
OK
Cancel
Help
Last changed Jan 01, 1986

Generators at 0 South 500 kV

Edit

On/Off-Line

Delete

New

Ref. angle= 0.

Power Flow Regulation

Hold V= 1.05 pu

At South 500 kV 0 (PV)

Regulates voltage Fixed P+jQ output

Done Help

Last changed Jan 01, 1996

ID= Unit rating= 100. MVA

Impedances (pu based on unit MVA)

Subtransient	0.	+j	0.1	Fill
Transient	0.	+j	0.1	
Synchronous	0.	+j	0.1	X_s
- sequence	0.	+j	0.1	X_2
o sequence	0.	+j	0.1	X_0

Neutral impedance (in actual Ohms)

0. +j 0.

Scheduled generation (MW)

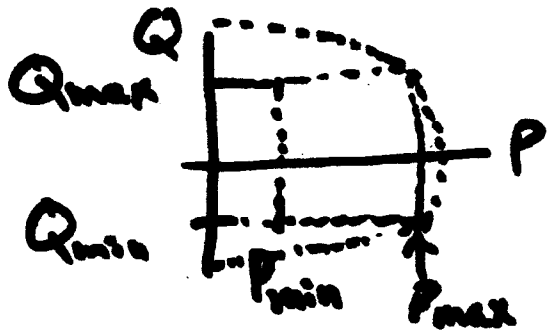
1390.

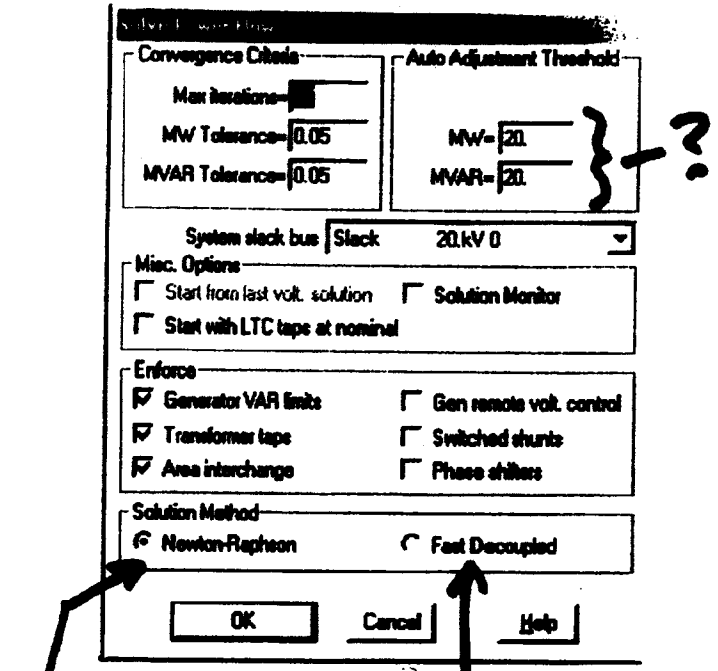
P and Q limits (MW and MVAR)

Pmax= 9999. Qmax= 9999.

Pmin= -9999. Qmin= -9999.

OK Cancel Help

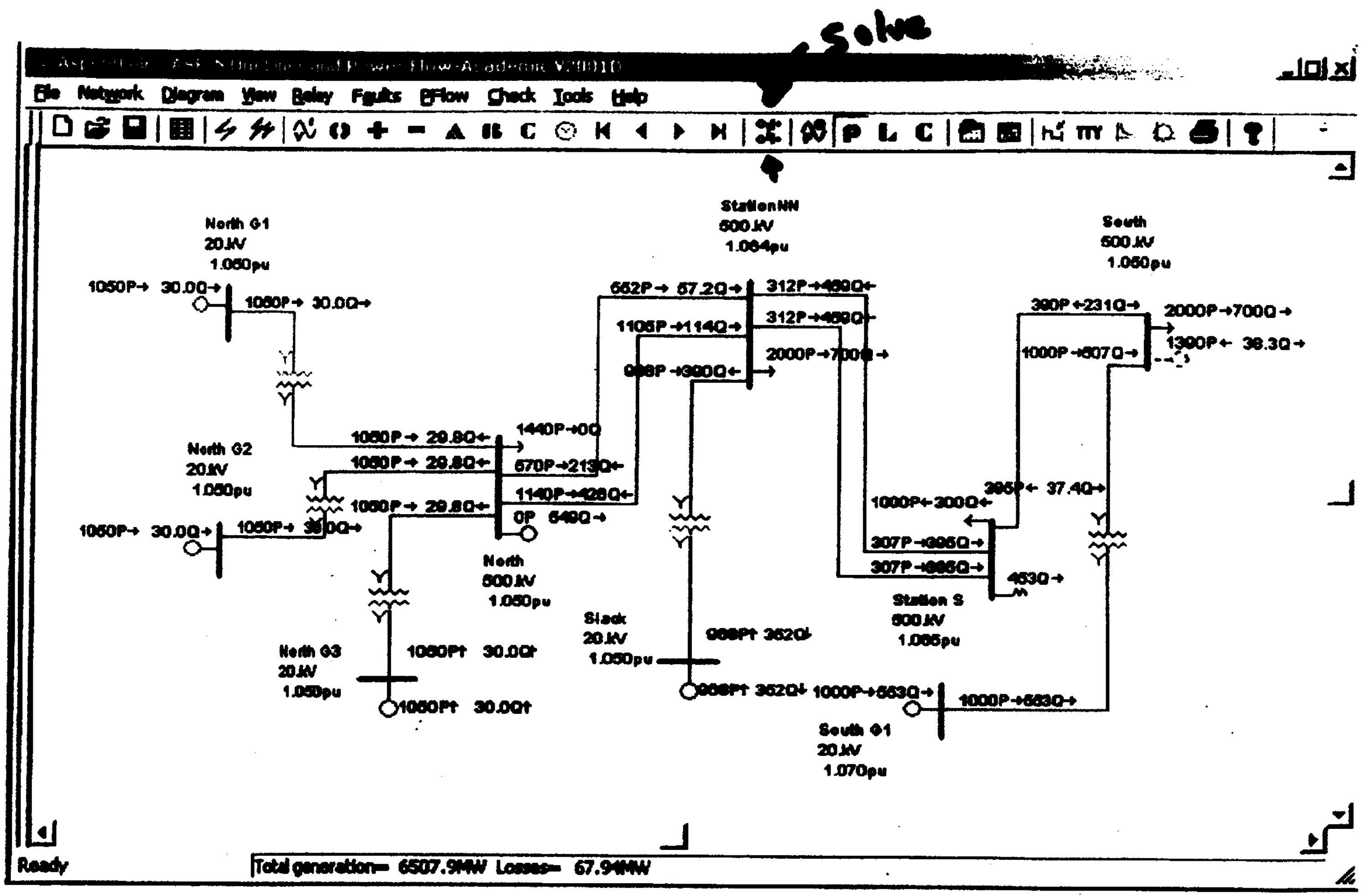




Full Jacobian

Main-diag submatrices of Jacobian

9


Solve
File Network Diagram View Relay Faults PFlow Check Tools Help
North G1
20.kV
1.050pu
1050P→ 30.0Q→
1050P→ 30.0Q→
North G2
20.kV
1.050pu
1050P→ 30.0Q→
North G3
20.kV
1.050pu
1050P↑ 30.0Q↑
North
500.kV
1.050pu
1050P→ 29.8Q←
1440P→0Q
570P→213Q←
1140P→428Q←
0P 549Q→
StationNN
500.kV
1.064pu
552P→ 57.2Q→
1105P→114Q→
312P→459Q←
2000P→700Q→
Slack
20.kV
1.050pu
South
500.kV
1.050pu
390P→231Q→
2000P→700Q→
1000P→507Q→
1390P← 38.3Q→
1000P←300Q←
395P← 37.4Q→
307P→395Q→
453Q→
Station S
500.kV
1.065pu
1000P→553Q→
South G1
20.kV
1.070pu
Ready
Total generation= 6507.9MW Losses= 67.94MW