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

Slack/Swing V-S bus

P, Q

\[ \Sigma P_{\text{area}} = 0 \]
\[ \Sigma Q_{\text{area}} = 0 \]

\( P, Q \) are "Slack" variables
Gen Bus (P-V Bus)

Solve for $Q_1$ & $S_1$

$2Q_{in} = 0$

Grid Input

$|V| \text{ is fixed.}$

If $Q_{min}$ or $Q_{max}$ are exceeded, change to PG
P-Q or Load Buses: Solve for \( V \) and \( S \)

Scheduled \( P, Q \) → \( V \) → \( VLS \) solve for bus voltage.

Grid Flows \([Y]\)

\[ jBc = Q = V^2 Bc \]

\[ \text{as} V: .95 \rightarrow 1.05 \]

\[ .9025 \rightarrow 1.102 \]
Voltage Collapse
is detected.
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 $V_k$, $\delta_k$, $P_k$, and $Q_k$ are input data and which are unknowns. Also, compute the elements of the second row of $Y_{bus}$.

**FIGURE 6.2**

Single-line diagram for Example 6.9

+ Assumed constant $P,Q$, i.e. don't change $V$ bus voltage.
### TABLE 6.1

Bus input data for Example 6.9*

<table>
<thead>
<tr>
<th>Bus</th>
<th>Type</th>
<th>( V ) per unit</th>
<th>( \delta ) degrees</th>
<th>( P_a ) per unit</th>
<th>( Q_a ) per unit</th>
<th>( P_l ) per unit</th>
<th>( Q_l ) per unit</th>
<th>( Q_{\text{min}} ) per unit</th>
<th>( Q_{\text{max}} ) per unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Swing</td>
<td>1.0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>4.0</td>
<td>-2.8</td>
</tr>
<tr>
<td>2</td>
<td>Load</td>
<td></td>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Constant</td>
<td>1.05</td>
<td>5.2</td>
<td>8.0</td>
<td>0.8</td>
<td>0.4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Load</td>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Load</td>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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

### TABLE 6.2

Line input data for Example 6.9

<table>
<thead>
<tr>
<th>Bus-to-Bus</th>
<th>( R' ) per unit</th>
<th>( X' ) per unit</th>
<th>( G' ) per unit</th>
<th>( B' ) per unit</th>
<th>Maximum MVA per unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-4</td>
<td>0.0090</td>
<td>0.100</td>
<td>0.25</td>
<td></td>
<td>12.0</td>
</tr>
<tr>
<td>2-5</td>
<td>0.0045</td>
<td>0.050</td>
<td></td>
<td></td>
<td>10.0</td>
</tr>
<tr>
<td>4-5</td>
<td>0.00225</td>
<td>0.025</td>
<td></td>
<td></td>
<td>12.0</td>
</tr>
</tbody>
</table>

### TABLE 6.3

Transformer input data for Example 6.9

<table>
<thead>
<tr>
<th>Bus-to-Bus</th>
<th>( R ) per unit</th>
<th>( X ) per unit</th>
<th>( G ) per unit</th>
<th>( B_{\text{m}} ) per unit</th>
<th>Maximum MVA per unit</th>
<th>Maximum TAP Setting per unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-5</td>
<td>0.00150</td>
<td>0.02</td>
<td>0.01</td>
<td>0</td>
<td>6.0</td>
<td></td>
</tr>
<tr>
<td>3-4</td>
<td>0.00075</td>
<td>0.01</td>
<td>0.01</td>
<td>0</td>
<td>10.0</td>
<td></td>
</tr>
</tbody>
</table>

### 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 \( \delta_3 \) are unknowns. For buses 2, 4, and 5, load buses, \( V_2 \), \( V_4 \), \( V_5 \) and \( \delta_2, \delta_4, \delta_5 \) are unknowns.
Transformers

*Zero unless LTC or PS, tap ratio #1.

\[
\begin{bmatrix}
K & x \\
L & x \\
x & x
\end{bmatrix}
\]

Add effect into \([Y]\).
Gen Var Limits

\[ \begin{align*}
R' & \quad jX' \\
G' & \quad \frac{1}{j\beta'}
\end{align*} \]
right click to enter params.

Alt- PrtScr ➔ active window
Ctl - PrtScr ➔ whole screen
Paste into document.
Bus Data

Name: 
Bus no.: 0
Location: North
Area no.: 1
Zone no.: 1
Bus Type: Real bus
Zone Style: Vertical bar
Symbol Style: Show ID on one-line diagram
State plane coordinates: X = 0, Y = 0
Last changed Jan 01, 1986

Transmission Line Data

0 Station NN 500 kV - 0 Station S 500 kV
Name: 
Ckt ID: 1
Length: 0.0
Kt: 
Type: 

Branch Parameters
Recompute from table
R = 0.006
X = 0.06
R0 = 0.006
X0 = 0.06

G1 = 0
B1 = 0
G2 = 0
B2 = 0
G10 = 0
B10 = 0
G20 = 0
B20 = 0

Current Ratings (A)
A: 0
B: 0
C: 0
D: 0

Metered at: Station NN 500 kV

OK Cancel Help

Last changed Jan 01, 1986
<table>
<thead>
<tr>
<th>Transformer Data</th>
<th>20 kV</th>
<th>500 kV</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Tap kV</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G1=20</td>
<td>G2=500</td>
<td></td>
</tr>
<tr>
<td>B1=0</td>
<td>B2=0</td>
<td></td>
</tr>
<tr>
<td>G10=0</td>
<td>G20=0</td>
<td></td>
</tr>
<tr>
<td>B10=0</td>
<td>B20=0</td>
<td></td>
</tr>
</tbody>
</table>

**Metered at:**

<table>
<thead>
<tr>
<th>South G1 20 kV</th>
<th>South 500 kV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zg1=0</td>
<td>Zg2=0</td>
</tr>
<tr>
<td>Zgn=0</td>
<td></td>
</tr>
</tbody>
</table>

Last changed Jan 01, 1986
## Generating Unit Info

<table>
<thead>
<tr>
<th>ID:</th>
<th>Unit rating: 100 MVA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Impedances (pu based on unit MVA)

- Subtransient: 0.1
- Transient: 0.1
- Synchronous: 0.1
- o sequence: 0.1
- i sequence: 0.1
- x:
- x:
- x:
- x:

### Neutral Impedance (in actual Ohms)

<table>
<thead>
<tr>
<th>Ohms</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1</td>
</tr>
</tbody>
</table>

### Scheduled generation (MW)

<table>
<thead>
<tr>
<th>MW</th>
</tr>
</thead>
<tbody>
<tr>
<td>130</td>
</tr>
</tbody>
</table>

### P and Q limits (MW and MVAR)

- P max: 8999.99, Q max: 9999.99
- P min: -8999.99, Q min: -9999.99

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**Diagram**

The diagram shows a rectangular coordinate system with axes labeled P and Q. The axes are labeled as follows:

- Q max: upper right corner
- Q min: lower right corner
- P max: upper left corner
- P min: lower left corner

The diagram illustrates the boundary lines for maximum and minimum values of P and Q.
- Full Jacobian
- Main-diag submatrices of Jacobian.