Problem Session 4

Protection From Failure (Real Time) - An outage of a - Trans line
- Transformer
- Bus
- Bus

Linear Power Flow "DC Power Flow"

\[ z = v + jx \]

\[ X_{ij} = \text{PU \ induced \ reactance.} \]

\[ P_{ij} = \frac{1}{X_{ij}} (\Theta_i - \Theta_j) \text{ [radians]} \]

100 MVA.

\[ P_n = 48 \text{ Mw} \]

\[ \frac{P_{pu}}{100} = 0.48 \]

\[ I_{12} = \frac{(V_1 - V_2)}{R} \]
\[ P_1 = P_{12} + P_{13} \]
\[ P_2 = -P_{12} + P_{23} \quad \alpha = P_{21} + P_{23} \]
\[ P_3 = -P_{13} - P_{23} \quad \alpha = P_{31} + P_{32} \]
\[ P_{12} = -P_{21} \]
\[ \frac{1}{x_{12}}(\theta_1 - \theta_2) = \frac{1}{x_{11}}(\theta_2 - \theta_1) \]
\[ P_1 = P_{12} + P_{13} \]
\[ P_2 = P_{21} + P_{23} \]
\[ P_3 = P_{31} + P_{32} \]

3 unknowns: \( \theta_1, \theta_2, \theta_3 \)
Ref Fixed θ
θ₁ = 0

\[ P_1 = P_{12} + P_{13} = \frac{1}{Y_{12}} (θ_1 - θ_2) + \frac{1}{Y_{13}} (θ_1 - θ_3) \]

\[ P_2 = P_{21} + P_{23} = \frac{1}{Y_{12}} (θ_2 - θ_1) + \frac{1}{Y_{23}} (θ_2 - θ_3) \]

\[ P_3 = P_{31} + P_{32} = \frac{1}{Y_{13}} (θ_3 - θ_1) + \frac{1}{Y_{23}} (θ_3 - θ_2) \]

Matrix \( B_x \)

\[
\begin{bmatrix}
1 & -\frac{1}{Y_{12}} & -\frac{1}{Y_{13}} \\
-\frac{1}{Y_{12}} & \frac{1}{Y_{12}Y_{13}} & -\frac{1}{Y_{13}} \\
-\frac{1}{Y_{13}} & -\frac{1}{Y_{23}} (\frac{1}{Y_{13}} + \frac{1}{Y_{23}})
\end{bmatrix}
\begin{bmatrix}
θ_1 \\
θ_2 \\
θ_3
\end{bmatrix} =
\begin{bmatrix}
P_1 \\
P_2 \\
P_3
\end{bmatrix}
\]

Matrix \( B_{alt} \)

\[
\begin{bmatrix}
1 & 0 & 0 \\
0 & (\frac{1}{Y_{12}} + \frac{1}{Y_{23}}) & -\frac{1}{Y_{23}} \\
0 & -\frac{1}{Y_{23}} (\frac{1}{Y_{12}} + \frac{1}{Y_{23}})
\end{bmatrix}
\begin{bmatrix}
θ_1 \\
θ_2 \\
θ_3
\end{bmatrix} =
\begin{bmatrix}
P_1 \\
P_2 \\
P_3
\end{bmatrix}
\]
A matrix Generator Shift Sensitivity

✓ PTDF Power Transfer Distribution Factors
LODF Line Outage Distribution Factors.

Ps

\[ P_{\text{nm}} (\text{with Trans}) = P_{\text{nm}}^0 + \text{PTDF} \cdot P_{\text{sr}} \]
LODF

\[ P_{ij}^* = P_{ij}^0 + \text{LODF} \cdot P_{nm} \]

HW4 3rd B

\[ \Delta f_i = a_{ij} \Delta P_j \]
\[ a_{ij} = \frac{1}{x_{ij}} \left( \frac{X_j}{X_{ij}} - \frac{X_i}{X_{ij}} \right) \]
$\begin{bmatrix} R_i \end{bmatrix} \rightarrow \begin{bmatrix} \alpha \cdot \beta \end{bmatrix} \rightarrow \begin{bmatrix} X \end{bmatrix} \quad \text{6}

X_{is} = \text{row}_i \cdot \text{col}_s \cdot X
X_{js} = \text{row}_j \cdot \text{col}_s \cdot X

PTDF = \frac{1}{S_{s,r} \cdot l} \left[ \left( \bar{X}_{is} - X_{ir} \right) - \left( \bar{X}_{js} - X_{jr} \right) \right] \quad \text{level i to j}

S = \text{Source Bus}
R = \text{Receive Bus} \quad l \text{ line to } j

LODF \quad l = i \text{ to } j \quad \text{Line Monitored}
R = n, m \quad \text{Line dropped}

\text{LODF} = PTDF \left( \sum_{n, m, e} \frac{1}{1 - PTDF_{n, m, j}} \right)

\bar{f} = f^0 + \text{LODF} \cdot f^0
\quad l, R
### Base Case

<table>
<thead>
<tr>
<th>FROM</th>
<th>TO</th>
<th>x</th>
<th>1/x</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>0.2</td>
<td>5</td>
</tr>
<tr>
<td>1</td>
<td>3</td>
<td>0.3</td>
<td>3.333333</td>
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<tr>
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<td>4</td>
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</tr>
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<td>4</td>
<td>0.4</td>
<td>2.5</td>
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### Flow Calculation Matrix

<table>
<thead>
<tr>
<th>Bus</th>
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<th>2</th>
<th>3</th>
<th>4</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>5</td>
<td>-5</td>
<td>0</td>
<td>0</td>
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<td>2</td>
<td>3.333333</td>
<td>0</td>
<td>-3.333333</td>
<td>0</td>
</tr>
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<td>3</td>
<td>3.333333</td>
<td>0</td>
<td>0</td>
<td>-3.333333</td>
</tr>
<tr>
<td>4</td>
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<td>3.333333</td>
<td>-3.333333</td>
<td>0</td>
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<tr>
<td>5</td>
<td>0</td>
<td>0</td>
<td>2.5</td>
<td>-2.5</td>
</tr>
</tbody>
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### Bx

11.667  -5  -3.333  -3.333333
-5  8.333333  -3.333  0
-3.333  -3.333  9.1667  -2.5
-3.333  0  -2.5  5.833333

### altBx

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<tr>
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<th>0</th>
<th>0</th>
<th>0</th>
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<tbody>
<tr>
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<td>8.333333</td>
<td>-3.333</td>
<td>0</td>
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<tr>
<td>0</td>
<td>-3.333</td>
<td>9.1667</td>
<td>-2.5</td>
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<tr>
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<td>0</td>
<td>-2.5</td>
<td>5.833333</td>
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### invaltBx

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<td>0.1437</td>
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<td>0</td>
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<td>0.0634</td>
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### Pnet

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<td>0.3</td>
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<tr>
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</tr>
<tr>
<td>-0.3</td>
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<tr>
<td>-0.3</td>
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</tbody>
</table>

### flows flows MW

<table>
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<th>FROM</th>
<th>TO</th>
<th>flows</th>
<th>flows MW</th>
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</thead>
<tbody>
<tr>
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<td>-8.873239</td>
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<td></td>
<td></td>
<td>0.152113</td>
<td>15.21127</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.23662</td>
<td>23.66197</td>
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<td></td>
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<td>0.211268</td>
<td>21.12676</td>
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<td></td>
<td>0.06338</td>
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### Theta

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<tbody>
<tr>
<td>-0.046</td>
</tr>
<tr>
<td>-0.071</td>
</tr>
</tbody>
</table>

### Flows in pu Flows in MW

1 2
1 3
1 4
2 3
3 4
Line outage of line 2-3

\[
\begin{array}{cccc}
\text{FROM} & \text{TO} & x & 1/x \\
1 & 2 & 0.2 & 5 \\
1 & 3 & 0.3 & 3.33333 \\
1 & 4 & 0.3 & 3.33333 \\
2 & 3 & 0.3 & 0 \\
3 & 4 & 0.4 & 2.5 \\
\end{array}
\]

\[
\begin{array}{cccc}
1 & 2 & 3 & 4 \\
5 & -5 & 0 & 0 \\
3.33333 & 0 & -3.333 & 0 \\
3.33333 & 0 & 0 & -3.333 \\
0 & 0 & 0 & 0 \\
0 & 0 & 2.5 & -2.5 \\
\end{array}
\]

\[
\begin{array}{cccc}
11.667 & -5 & -3.333 & -3.33333 \\
-5 & 5 & 0 & 0 \\
-3.333 & 0 & 5.8333 & -2.5 \\
-3.333 & 0 & -2.5 & 5.83333 \\
\end{array}
\]

\[
\begin{array}{cccc}
1 & 0 & 0 & 0 \\
0 & 5 & 0 & 0 \\
0 & 0 & 5.8333 & -2.5 \\
0 & 0 & -2.5 & 5.83333 \\
\end{array}
\]

\[
\begin{array}{cccc}
1 & 0 & 0 & 0 \\
0 & 0.2 & 0 & 0 \\
0 & 0 & 0.21 & 0.09 \\
0 & 0 & 0.09 & 0.21 \\
\end{array}
\]

\[
\begin{array}{cccc}
P_{\text{net}} & \Theta & \text{flows} & \text{flows MW} \\
0.3 & 0 & -0.3 & -30 \\
0.3 & 0.06 & 0.3 & 30 \\
-0.3 & -0.09 & 0 & \text{out} \\
-0.3 & -0.09 & 0 & \text{out} \\
3E-17 & 3E-15 & 3 & 4 \\
\end{array}
\]

Using LODF

\[
P_{13\text{new}} = P_{13\text{orig}} + 0.7 \times P_{23\text{orig}} \\
30 = 15.211 + 0.7 \times 21.127
\]
15.21 + 23.66 - 8.87 = 30
Use LOOF calc. Plus on line 1-3 with Lin 23 out.

Orig. Plans. \( P_{13}^o = 15.21 \)
\( P_{23}^o = 21.127 \)

\( \text{LOOF} = 0.7 \)
\( 1-3, 2-3 \)
\( \begin{array}{c|c}
           & 1     \\
\hline
\text{Min} & \text{drop} \\
\hline
\end{array} \)

\( P_{13}^* = 15.21 + 0.7 \times 21.127 = 30.0 \)

Outage on 1-2, 1-3, 1-4

Any of them cause overload?

\( F_{14}^* = F_{14}^o + \text{LOOF} \cdot F_{13}^o \)
\( \leq 25 \text{ MW} \)
\( F_{14}^* = 23.6 + 0.4167 \times 15.21 = 30.0 \text{ min} \)

Overload

\( F_{3-4}^* = F_{3-4}^o \cdot F_{14}^o \)
\( 6.34 + 1 \cdot 23.66 = 30 \text{ MW} \)

Overload
Gen 1 will reduce output to reduce load.

Until No overload with output.

(First continuing overload)

\[ F_{i-4} = F_{i-4}^0 + PTDF \Delta P \]

\[ F_{i-4}^0 = F_{i-4} \text{ (load 1-4, 1-4, 1-4)} \]

\[ F_{i-4} = (F_{i-4}^0 + PTDF \Delta P) + LUOF (F_{i-3} + PTDF \Delta P) \]

Flow on 1-4 with \( \Delta P \) (Red gen Bus) Red (Red Bus 4)

AND output of line 1-2
Consider the power system network below. Both generators are at 30 MW output and both loads are consuming 30 MW. Bus 1 is the reference bus.

![Diagram of the power system network with buses labeled 1, 2, 3, 4, and 5, and lines connecting them with power flow indications.]

The data for this network is as follows:

<table>
<thead>
<tr>
<th>From Bus</th>
<th>To Bus</th>
<th>$x$</th>
<th>MW Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>0.20</td>
<td>35.0</td>
</tr>
<tr>
<td>1</td>
<td>3</td>
<td>0.30</td>
<td>35.0</td>
</tr>
<tr>
<td>1</td>
<td>4</td>
<td>0.30</td>
<td>25.0</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
<td>0.30</td>
<td>40.0</td>
</tr>
<tr>
<td>3</td>
<td>4</td>
<td>0.40</td>
<td>25.0</td>
</tr>
</tbody>
</table>

The initial power flows are calculated with a DC Power Flow and result in the base flows below. The line flow limits are also shown with the percent loading.

**BASE TRANSMISSION LOADING**

<table>
<thead>
<tr>
<th>Path</th>
<th>From</th>
<th>To</th>
<th>Low Flow</th>
<th>Flow</th>
<th>High Flow</th>
<th>Percent Loading</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>2</td>
<td>-35.0</td>
<td>-8.87</td>
<td>35.0</td>
<td>25.4</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>3</td>
<td>-35.0</td>
<td>15.21</td>
<td>35.0</td>
<td>43.5</td>
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<tr>
<td>3</td>
<td>1</td>
<td>4</td>
<td>-25.0</td>
<td>23.66</td>
<td>25.0</td>
<td>94.6</td>
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<tr>
<td>4</td>
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<td>21.13</td>
<td>40.0</td>
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<tr>
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<td>3</td>
<td>4</td>
<td>-25.0</td>
<td>6.34</td>
<td>25.0</td>
<td>25.4</td>
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</tbody>
</table>
### AFAC T MATRIX

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monitored</td>
<td>1 to 2</td>
<td>1 to 3</td>
<td>1 to 4</td>
<td>2 to 3</td>
</tr>
<tr>
<td>Line</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
</tr>
<tr>
<td></td>
<td>-0.7183</td>
<td>-0.1972</td>
<td>-0.0845</td>
<td>0.2817</td>
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<tr>
<td></td>
<td>-0.2958</td>
<td>-0.4930</td>
<td>-0.2113</td>
<td>-0.2958</td>
</tr>
<tr>
<td></td>
<td>-0.1268</td>
<td>-0.2113</td>
<td>-0.6620</td>
<td>-0.1268</td>
</tr>
</tbody>
</table>

### POWER TRANSFER DISTRIBUTION FACTOR (PTDF) MATRIX

<table>
<thead>
<tr>
<th></th>
<th>1 to 3</th>
<th>1 to 4</th>
<th>2 to 3</th>
<th>2 to 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monitored</td>
<td>1 to 2</td>
<td>1 to 3</td>
<td>1 to 4</td>
<td>2 to 3</td>
</tr>
<tr>
<td>Line</td>
<td>0.2958</td>
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<td>0.2113</td>
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### LINE OUTAGE DISTRIBUTION FACTOR (LODF) MATRIX

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<th>1 to 3</th>
<th>1 to 4</th>
<th>2 to 3</th>
<th>2 to 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monitored</td>
<td>1 to 2</td>
<td>1 to 3</td>
<td>1 to 4</td>
<td>2 to 3</td>
<td>2 to 4</td>
</tr>
<tr>
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</table>
HW4 PROBLEM 1

1) Formula for calculating the A matrix:

Note that: line \( \ell \) goes from bus \( i \) to bus \( j \) and \( x_\ell \) is the line’s inductive reactance in per unit.

\[
a_{is} = \frac{1}{x_\ell} (X_{is} - X_{js}) \text{ then } \Delta f_\ell = a_{is} \Delta P_s, \text{ that is for a change in power at bus } s \text{ of } \Delta P_s \text{ the change in line flow } \ell \text{ is } \Delta f_\ell \text{ and is found by multiplying the change in power at bus } s \text{ times the a factor. Note that when the bus power at bus } s \text{ is changed there is a compensating and opposite change in power on the reference or swing bus.}
\]

The terms \( X \) are from the \( X \) matrix and the subscripts are for the \( X \) matrix row and column, thus, \( X_{is} \) is the term in row i column s of the \( X \) matrix.

2) Formula for calculating the PTDF factors.

\[
PTDF_{s,r,\ell} = \frac{1}{x_\ell} \left( (X_{is} - X_{ir}) - (X_{js} - X_{jr}) \right)
\]

if \( s \) is the reference bus, \( X_{is} = 0 \) and \( X_{js} = 0 \)

if \( r \) is the reference bus, \( X_{ir} = 0 \) and \( X_{jr} = 0 \)

if \( i \) is the reference bus, \( X_{is} = 0 \) and \( X_{ir} = 0 \)

if \( j \) is the reference bus, \( X_{js} = 0 \) and \( X_{jr} = 0 \)

The formula for \( PTDF_{s,r,\ell} \) is the PTDF for the effect on line \( \ell \) of a transaction from source bus \( s \) to receiving bus \( r \).

3) Formula for calculating the Line outage distribution factors, LODF.

For the LODF we introduce line \( k \) which goes from bus \( n \) to bus \( m \). Line \( k \) will be dropped and the LODF gives us the effect of line \( k \) out on the flow on line \( \ell \) which goes from bus \( i \) to bus \( j \) as before.

The LODF giving the change in flow on line \( \ell \) for an outage of line \( k \) is

\[
LODF_{\ell,k} = PTDF_{n,m,\ell} \left( \frac{1}{1 - PTDF_{n,m,k}} \right)
\]

So that:

\[
\Delta f_\ell = LODF_{\ell,k} P_{nm}
\]

Thus we simply multiply the preoutage flow on line \( k \), \( P_{nm} \) or \( f_\ell^0 \), times \( LODF_{\ell,k} \) to get the change in flow on line \( \ell \), then the new flow on line \( \ell \), \( \tilde{f}_\ell \), with an outage on line \( k \) is: (where \( f_\ell^0 \) is the preoutage flow, i.e. flow before the outage, while \( \tilde{f}_\ell \) is the flow after the outage.) \( \tilde{f}_\ell = f_\ell^0 + LODF_{\ell,k} f_k^0 \)
a) In this problem we are only concerned with outages on lines 1-2, 1-3 and 1-4. Do any of these outages, taken one outage at a time, result in overloads? If so how much and what lines are overloaded.

b) The generator at bus 1 is going to reduce its output and at the same time the load at bus 4 is going to reduce its load until there are no overloads due to the lines listed in part a above. How much should the load on bus 4 and the generation on bus 1 be reduced to eliminate all overloads.
Problem 2

A) Overloads: Drop line 1-3, overload on 1-4

\[ F_{14}^{\text{new}} = F_{1-4} + \text{LODF} \times F_{13} \]

\[ = 23.66 + 0.4167 \times 15.21 = 30 \text{ MW} \]

Drop line 1-4 overload 3-4

\[ F_{3-4}^{\text{new}} = F_{34} + \text{LODF} \times F_{1-4} \]

\[ = 6.34 + 1.0 \times 23.66 = 30 \text{ MW} \]

B) Fail line 1-4

\[ F_{1-4}^{\text{after Trans}} = F_{1-4} + \text{PTDF} \times \Delta P \]

\[ F_{1-4}^{\text{final}} = (F_{1-4} + \text{PTDF} \times \Delta P) + \text{LODF}(F_{13} + \text{PTDF} \times \Delta P) \]

\[ = (23.66 + 0.662 \times \Delta P) + 0.4167 (15.21 + 0.2113 \Delta P) \]

\[ 2.5 = (23.66 + 0.4167 \times 15.21) + (0.662 + 0.4167 \times 0.2113) \Delta P \]

\[ 2.5 = 30 + 0.75 \Delta P \]

\[ \Delta P = -6.666 \text{ MW} \]
Prob 2) B cont

For line 3-4

\[ P_{3-4} = \left( \frac{\Delta P}{F_{3-4}} \right) + \text{load} \left( \frac{F_{1-4} \cdot \text{TD} \cdot \Delta P}{1-4} \right) \]

\[ = \left( \frac{6.34 + 3.38 \, \Delta P}{3414} \right) + 1.0 \left( \frac{23.66 + 6.62 \, \Delta P}{1-4} \right) \]

\[ 25 = 30 + 1.0 \, \Delta P \]

\[ \Delta P = -5 \]

Answer to part B:

\[ \Delta P \] is -6.666

So reduce load 4 by 6.666 MW

and Bus 1 by 6.666 MW.
» runsecurity

Pinj =

0.3000  0.3000  -0.3000  -0.3000

BASE TRANSMISSION LOADING

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************** OVERLOADS DETECTED **************

**********************************************************************************

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runsecurity

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**CONTINGENCY OVERLOAD**
- drop 1 to 3 mon 1 to 4: contflow 30.00, contlimit 25.0, rating 25.0, overload% 120.0
- drop 1 to 4 mon 3 to 4: contflow 30.00, contlimit 25.0, rating 25.0, overload% 120.0
- drop 2 to 3 mon 1 to 4: contflow 30.00, contlimit 25.0, rating 25.0, overload% 120.0
- drop 3 to 4 mon 1 to 4: contflow 30.00, contlimit 25.0, rating 25.0, overload% 120.0

************** OVERLOADS DETECTED **************
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runsecurity

BASE TRANSMISSION LOADING LINE 2-3 OUT

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**CONTINGENCY OVERLOAD**
- drop 1 to 2 mon 1 to 3: contflow 50.00, contlimit 35.0, rating 35.0, overload% 142.9
- drop 1 to 2 mon 1 to 4: contflow 50.00, contlimit 25.0, rating 25.0, overload% 200.0
- drop 1 to 3 mon 1 to 4: contflow 60.00, contlimit 25.0, rating 25.0, overload% 240.0
- drop 1 to 3 mon 3 to 4: contflow -30.00, contlimit 25.0, rating 25.0, overload% 120.0
- drop 1 to 4 mon 1 to 3: contflow 60.00, contlimit 35.0, rating 35.0, overload% 171.4
- drop 1 to 4 mon 3 to 4: contflow 30.00, contlimit 25.0, rating 25.0, overload% 120.0
- drop 3 to 4 mon 1 to 4: contflow 30.00, contlimit 25.0, rating 25.0, overload% 120.0

************** OVERLOADS DETECTED **************
-----------------------------------------------