1. Assume a three bus power system with buses 1, 2, and 3 with generators at each bus and bus 3 the system slack. Also assume there are three lossless lines with the line between 1 and 2 having a per unit impedance of j0.1, the line between 2 and 3 a per unit impedance of j0.2 and the line between 1 and 3 a per unit impedance of j0.3. Calculate the injection shift matrix.

   $\tilde{B}$ = -diag(10 5 3.3)

   $$A = \begin{bmatrix} 1 & -1 \\ 0 & 1 \\ 1 & -1 \end{bmatrix}$$

   $$B' = A^T \tilde{B} A = \begin{bmatrix} -13.33 & 10 \\ 10 & -15 \end{bmatrix}$$

   $$\psi = \tilde{B} A [B']^{-1} = \begin{bmatrix} 0.5025 & -0.3317 \\ 0.5025 & 0.6683 \\ 0.4975 & 0.3317 \end{bmatrix}$$

Problems 2 to 6 make use of the ProbelmSet4_B7Flat_DC case, which is available on the course website. This case is a modified version of the B7Flat case in which 1) the lines are modeled just using reactances, 2) the case is solved using the dc power flow, and 3) some of the line limits have been increased. Assume the initial injections for this case to be the base case values. Bus 7 is the system slack. For consistency please use the line numbering and from/to bus orientations given for the case. For convenience the line ordering is given at the end of this problem set. That is, the line from bus 1 to bus 2 is #1, the line from bus 1 to bus 3 is #2, etc.

2. Determine the UTC in both directions (to the nearest 5 MW) for a transfer from bus 4 to the system slack (bus 7). Consider all single line contingencies. For convenience the eleven single element contingencies have already been defined for you.

Solution: Switch OFF all AGCs before continegency analysis. Approximate results are shown:

Initial generation at bus 4: 50 MW   From bus 4 → 7

Case/ Contingency	Line violation (@100%)	Bus 4 generation	Transaction change (UTC)
	From bus→ To bus	MW	MW
Base case	4 → 5	200	150
Line 1 out	4 → 5	135	85
Line 2 out	4 → 5	220	170
Line 3 out	4 → 5	206	156
Line 4 out	4 → 5	200	150
Line 5 out	4 → 5	87	37
Lint 6 out	4 → 5	120	70
Line 7 out	4 → 5	154	104
Line 8 out	2 → 5	176	126
Line 9 out	2 → 6	250	200
Line 10 out	4 → 5	180	130
Line 11 out	4 → 5	180	130

The UTC between bus 4 and system slack bus 7 is the minimum UTC. This equals 37 MW which occurs for single line contingencies for line 5 outages.

Initial generation at bus 4: 50 MW   From bus 7 → 4

Case/ Contingency	Line violation (@100%)	Bus 4 generation	Transaction change (UTC)
	From bus→ To bus	MW	MW
Base case	2 → 3	-103	-153
Line 1 out	3 → 4	-122	-172
Line 2 out	2 → 3	21	-29
Line 3 out	2 → 4	-45	-95
Line 4 out	2 → 3	8	-45
Line 5 out	2 → 3	-71	-121
Lint 6 out	2 → 3	-112	-162
Line 7 out	2 → 4	-65	-115
Line 8 out	2 → 3	-58	-108
Line 9 out	2 → 3	-58	-108
Line 10 out	2 → 3	-105	-155
Line 11 out	2 → 3	-105	-155

The UTC between bus 7 and system slack bus 4 is the minimum UTC. This equals 29 MW which occurs for single line contingencies for line 2 outages.

3. Using a matrix package such as Matlab or the free scilab, calculate the ISF matrix.

```
clc; clear all; close all;
x = [0.06 0.24 0.18 0.18 0.12 0.06 0.03 0.24 0.06 0.24 0.24];
b = 1./x;
B_tilde = -diag(b);
A = [1 -1 0 0 0 0;
        1  0 -1 0 0 0;
        0 1 -1 0 0 0;
        0 1 0 -1 0 0;
        0 1 0 0 -1 0;
        0 1 0 0 0 -1;
        0 0 1 -1 0 0;
        0 0 0 1 -1 0;
        0 0 0 0 -1 0;
        0 0 0 0 0 1;
        0 0 0 0 0 1]; %Since Bus 7 is the slack bus, the columns
B_prime = transpose(A)*B_tilde*A;
psi_l_n = B_tilde*A*(B_prime)^-1
```

```
d Window
   0.8108   -0.0314    0.1799    0.1362    0.0105   -0.0210
   0.1892    0.0314   -0.1799   -0.1362   -0.0105    0.0210
  -0.0180    0.0524   -0.2998   -0.2270   -0.0175    0.0349
   0.0105    0.0664   -0.2130   -0.2875   -0.0221    0.0442
   0.3789    0.3999    0.2951    0.2672   -0.1333    0.2666
   0.4395    0.4499    0.3976    0.3836    0.1834   -0.3667
   0.1711    0.0838    0.5204   -0.3632   -0.0279    0.0559
   0.1816    0.1502    0.3073    0.3492   -0.0501    0.1001
  -0.5605   -0.5501   -0.6024   -0.6164   -0.8166   -0.3667
   0.2197    0.2250    0.1988    0.1918    0.0917    0.3166
   0.2197    0.2250    0.1988    0.1918    0.0917    0.3166
```

4. Calculate the LODF for the line between buses 1 and 3 for an outage of the line between buses 2 and 5.

```
clc; clear all; close all;
x = [0.06 0.24 0.18 0.18 0.12 0.06 0.03 0.24 0.06 0.24 0.24];
b = 1./x;
B_tilde = -diag(b);
A = [1 -1 0 0 0 0;
        1  0 -1 0 0 0;
        0 1 -1 0 0 0;
        0 1 0 -1 0 0;
        0 1 0 0 -1 0;
        0 1 0 0 0 -1;
        0 0 1 -1 0 0;
        0 0 0 1 -1 0;
        0 0 0 0 -1 0;
        0 0 0 0 0 1;
        0 0 0 0 0 1]; %Since Bus 7 is the slack bus, the columns indicate bus1-6, rows are
B_prime = transpose(A)*B_tilde*A;
psi_l_n = B_tilde*A*(B_prime)^-1


for i = 1:11
    LODF(i,:) = [i, ((psi_l_n(i,2) - psi_l_n(i,5))/(1 - (psi_l_n(5,2) - psi_l_n(5,5))))];
end
LODF(5,2) = -1;

header = {'Line', 'LODF'};
result = dataset({LODF, header{:}})
```

Line	LODF
1	-0.089776
2	0.089776
3	0.14963
4	0.18953
5	-1
6	0.57107
7	0.2394
8	0.42893
9	0.57107
10	0.28554
11	0.28554

The LODF for line 2 (from bus 1 to 3) is 0.089776.

5. Calculate the LODF for the line between buses 1 and 3 for the double outage of the line between buses 2 and 5 and the line between buses 4 and 5.

$$d_2^5 = 0.0898$$
$$d_2^8 = -0.2097$$
$$d_8^5 = 0.4289$$
$$d_5^8 = 0.6680$$

$$[0.0898 \quad -0.2097]\begin{bmatrix} 1 & -0.668 \\ -0.4289 & 1 \end{bmatrix}^{-1} = [-0.0002 - 0.2098]$$

6. Calculate the outage transfer distribution factor for a transfer between bus 4 to the system slack (bus 7) for the contingent outage of the line between buses 2 and 4.

$$\left(\psi_l^{(w)}\right)^k = \psi_l^{(w)} + d_l^k \psi_k^{(w)}$$

Line	LODF (d_l^k)	PTDF ($\psi_l^{(w)}$)	OTDF ($\left(\psi_1^{(w)}\right)^4$)
1	-0.2595	0.1362	0.2108
2	0.2595	-0.1362	-0.2108
3	0.4324	-0.2270	-0.3513
4	-1	-0.2875	0
5	0.2054	0.2672	0.2081
6	0.1027	0.3836	0.3540
7	0.6919	-0.3632	-0.5621
8	-0.3081	0.3492	0.4378
9	0.1027	-0.6164	-0.6459
10	0.0514	0.1918	0.1770
11	0.0514	0.1918	0.1770

7. In PowerWorld load the case TSGC_2000_HW4. This is the 2000 bus Texas case seen earlier, except now three 500 kV lines have tripped in the Fort Worth area because of a tornado. This has caused two transmission line overloads. Using sensitivity analysis, in this problem your job is to determine the best generation adjustment (redispatch) generation to remove the line overloads. For your optimization cost function, assume all generator changes have an equal incremental cost. Be sure to enforce generator maximum limits in your solution; however, you may drop generators to zero if needed.

   Various strategies are acceptable.