Lab Six (Part B)
Power Systems Analysis
EECE5682

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Abstract

The purpose of this laboratory experiment is to expand on the ideas from part (a). The same 30-bus system is explored, this time through the lens of contingency analysis. After running various outage cases, possible solutions are proposed, if necessary.

KEYWORDS: 30-bus system, contingency analysis, outage, possible solution

1 Introduction & Objectives

We begin by reconstructing the 30-bus system provided in Lab 6a in the Power Education Toolbox (PET) program. The system looks as follows:

Figure 1: The 30-Bus System

2 Experimentation

2.1 Part 1

We may run the initial contingency case solution to get:

Power Flow Solution - Base Case

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Power Flow Case Title :
Base MVA :  100.0 MVA

          CONVERGENCE SUMMARY
 ITER            DELP             DELQ

  0.0          0.933447
  0.5                           0.833339
  1.0          0.176630
  1.5                           0.045733
  2.0          0.010686
  2.5                           0.001978
  3.0          0.001196
  3.5                           0.155632
  4.0          0.055377
  4.5                           0.014145
  5.0          0.002026
  5.5                           0.086757
  6.0          0.020793
  6.5                           0.007858
  7.0          0.001000
  7.5                           0.000315
  8.0          0.000123


BUS   VOLTAGE   ANGLE        GENERATION               LOAD
NO.    PU     DEG      MW       MVAR       MW        MVAR


  30  0.9409   -25.62     0.00000     0.00000    10.60000     1.90000
  TO-BUS    29       -3.66946 MW    -0.54402 MVAR
  TO-BUS    27       -6.92770 MW    -1.35613 MVAR

  29  0.9530   -24.64     0.00000     0.00000     2.40000     0.90000
  TO-BUS    27       -6.10682 MW    -1.51441 MVAR
  TO-BUS    30        3.70675 MW     0.61448 MVAR

  27  0.9740   -23.28     0.00000     0.00000     0.00000     0.00000
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TO-BUS    25      24.61030 MW     3.24511 MVAR
TO-BUS    29       6.20263 MW     1.69542 MVAR
TO-BUS    30       7.10794 MW     1.69538 MVAR
TO-BUS    28     -37.92484 MW    -6.63438 MVAR

28  0.9803   -14.52     0.00000     0.00000     0.00000     0.00000
TO-BUS     6     -34.47901 MW    -7.11982 MVAR
TO-BUS     8      -3.45216 MW    -5.70286 MVAR
TO-BUS    27      37.92484 MW    12.82219 MVAR

26  0.9215   -26.76     0.00000     0.00000     3.50000     2.30000
TO-BUS    25      -3.49996 MW    -2.29981 MVAR

24  0.9841   -22.32     0.00000     0.00000     8.70000     6.70000
TO-BUS    25      20.46210 MW     1.92591 MVAR
TO-BUS    23      -9.39006 MW    -1.76915 MVAR
TO-BUS    22     -19.77720 MW    -2.69155 MVAR

25  0.9407   -26.27     0.00000     0.00000    40.00000     0.00000
TO-BUS    26       3.55250 MW     2.37829 MVAR
TO-BUS    27     -23.90032 MW    -1.88947 MVAR
TO-BUS    24     -19.63991 MW    -0.49003 MVAR

23  1.0018   -20.99     0.00000     0.00000     3.20000     1.60000
TO-BUS    24       9.51451 MW     2.02370 MVAR
TO-BUS    15     -12.71510 MW    -3.62356 MVAR

14  1.0303   -19.48     0.00000     0.00000     6.20000     1.60000
TO-BUS    15       3.25566 MW     0.66371 MVAR
TO-BUS    12      -9.45480 MW    -2.26370 MVAR

15  1.0221   -19.75     0.00000     0.00000     8.20000     2.50000
TO-BUS    18       6.14089 MW     1.63033 MVAR
TO-BUS    12     -23.99854 MW    -7.46268 MVAR
TO-BUS    23      12.88927 MW     3.97539 MVAR
TO-BUS    14      -3.23267 MW    -0.64294 MVAR

18  1.0122   -20.40     0.00000     0.00000     3.20000     0.90000
TO-BUS    19       2.89954 MW     0.64589 MVAR
TO-BUS    15      -6.09942 MW    -1.54589 MVAR

12  1.0474   -18.34     0.00000     0.00000    11.20000     7.50000
TO-BUS    16       9.22988 MW     4.03808 MVAR
TO-BUS    13       0.00000 MW   -17.55703 MVAR
TO-BUS     4     -54.38861 MW    -4.72336 MVAR
TO-BUS    14       9.56441 MW     2.49155 MVAR
TO-BUS    15      24.39883 MW     8.25116 MVAR

19  1.0095   -20.58     0.00000     0.00000     9.50000     3.40000
TO-BUS    20      -6.60557 MW    -2.76522 MVAR
TO-BUS    18      -2.89404 MW    -0.63477 MVAR

20  1.0136   -20.39     0.00000     0.00000     2.20000     0.70000
TO-BUS    10      -8.82269 MW    -3.49944 MVAR
TO-BUS    19       6.62268 MW     2.79944 MVAR

22  1.0126   -20.47     0.00000     0.00000     0.00000     0.00000
TO-BUS    21      -6.94790 MW     1.15516 MVAR
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TO-BUS    10     -13.30322 MW    -4.58283 MVAR
TO-BUS    24      20.25027 MW     3.42789 MVAR

21  1.0132   -20.37     0.00000     0.00000    17.50000    11.20000
TO-BUS    10     -24.45345 MW   -10.05601 MVAR
TO-BUS    22       6.95351 MW    -1.14374 MVAR

10  1.0291   -19.55     0.00000     0.00000     5.80000     2.00000
TO-BUS     9     -35.83905 MW    -7.21736 MVAR
TO-BUS    17       3.38328 MW     3.83161 MVAR
TO-BUS    21      24.69046 MW    10.56612 MVAR
TO-BUS    22      13.44359 MW     4.87224 MVAR
TO-BUS     6     -20.38077 MW     2.38699 MVAR
TO-BUS    20       8.90476 MW     3.68269 MVAR

17  1.0249   -19.64     0.00000     0.00000     9.00000     5.80000
TO-BUS    10      -3.37529 MW    -3.81076 MVAR
TO-BUS    16      -5.62431 MW    -1.98913 MVAR

16  1.0315   -19.11     0.00000     0.00000     3.50000     1.80000
TO-BUS    17       5.64206 MW     2.05428 MVAR
TO-BUS    12      -9.14246 MW    -3.85426 MVAR

 4  0.9947   -11.19     0.00000     0.00000     7.60000     1.60000
TO-BUS    12      54.38861 MW    11.67787 MVAR
TO-BUS     6      86.87729 MW   -13.48010 MVAR
TO-BUS     2     -51.84300 MW    -4.57497 MVAR
TO-BUS     3     -97.02402 MW     4.77690 MVAR

13  1.0709   -18.34     0.00000    17.93602     0.00000     0.00000
TO-BUS    12       0.00000 MW    17.95037 MVAR

 1  1.0600     0.00   309.94966     0.96510     0.00000     0.00000
TO-BUS     2     204.73617 MW   -10.37284 MVAR
TO-BUS     3     105.21348 MW    11.39074 MVAR

 2  1.0331    -6.25    40.00000    50.00000    21.70000    12.70000
TO-BUS     4      53.39569 MW     5.52229 MVAR
TO-BUS     5      88.79711 MW     2.53803 MVAR
TO-BUS     6      73.65976 MW     3.17213 MVAR
TO-BUS     1    -197.56407 MW    26.06802 MVAR

 9  1.0375   -17.44     0.00000     0.00000     0.00000     0.00000
TO-BUS    11       0.00000 MW   -22.23719 MVAR
TO-BUS    10      35.83905 MW     8.60558 MVAR
TO-BUS     6     -35.83907 MW    13.63156 MVAR

 6  0.9905   -13.37     0.00000     0.00000     0.00000     0.00000
TO-BUS     9      35.83907 MW   -10.79060 MVAR
TO-BUS    10      20.38077 MW    -0.17634 MVAR
TO-BUS     8      33.61294 MW    -8.76757 MVAR
TO-BUS     7      32.11109 MW    -4.71797 MVAR
TO-BUS     2     -70.69142 MW     2.00484 MVAR
TO-BUS    28      34.69547 MW     6.62468 MVAR
TO-BUS     4     -85.94911 MW    15.82252 MVAR

11  1.0821   -17.44     0.00000    23.18148     0.00000     0.00000
TO-BUS     9       0.00000 MW    23.19269 MVAR
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```
 7  0.9854   -14.98     0.00000     0.00000    22.80000    10.90000
TO-BUS     5       9.02983 MW   -14.83297 MVAR
TO-BUS     6     -31.82635 MW     3.93322 MVAR

 5  0.9976   -15.96     0.00000    40.00000    94.20000    19.00000
TO-BUS     7      -8.90043 MW    13.15364 MVAR
TO-BUS     2     -85.29980 MW     7.84448 MVAR

 8  0.9900   -14.25     0.00000    40.00000    30.00000    30.00000
TO-BUS    28       3.46884 MW     1.60103 MVAR
TO-BUS     6     -33.46626 MW     8.39842 MVAR

 3  1.0063    -9.04     0.00000     0.00000     2.40000     1.20000
TO-BUS     4      98.28346 MW    -2.00165 MVAR
TO-BUS     1    -100.68500 MW     0.80229 MVAR



FROM AREA

             TO   AREA   MW FLOW  MVAR FLOW
```

2.2 Contingency Analysis

2.2.1 Line 2-5 Outage

Power Flow Solution - Line 2-5 Outage Case

```
Power Flow Case Title :
Base MVA :  100.0 MVA

          CONVERGENCE SUMMARY
 ITER            DELP              DELQ

  0.0          0.971534
  0.5                            0.839859
  1.0          0.172544
  1.5                            0.077123
  2.0          0.043412
  2.5                            0.010507
  3.0          0.011001
  3.5                            0.002761
  4.0          0.002893
  4.5                            0.398648
  5.0          0.105256
  5.5                            0.035385
  6.0          0.033721
  6.5                            0.013974
  7.0          0.012949
  7.5                            0.002580
  8.0          0.005723
  8.5                            0.147046
```

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 9.0          0.077351
 9.5                           0.017125
10.0          0.032503
10.5                           0.007472
11.0          0.021842
11.5                           0.004210
12.0          0.014130
12.5                           0.002854
13.0          0.009181
13.5                           0.001841
14.0          0.005988
14.5                           0.001207
15.0          0.003919
15.5                           0.000791
16.0          0.002572
16.5                           0.000519
17.0          0.001691
17.5                           0.000342
18.0          0.001114
18.5                           0.000225
19.0          0.000734
```

BUS NO.	VOLTAGE PU	ANGLE DEG	GENERATION MW	GENERATION MVAR	LOAD MW	LOAD MVAR
30	0.8230	-33.65	0.00000	0.00000	10.60000	1.90000
TO-BUS	29		-3.66970 MW	-0.54855 MVAR		
TO-BUS	27		-6.92386 MW	-1.35194 MVAR		
29	0.8370	-32.38	0.00000	0.00000	2.40000	0.90000
TO-BUS	27		-6.11761 MW	-1.54061 MVAR		
TO-BUS	30		3.71846 MW	0.64068 MVAR		
27	0.8611	-30.63	0.00000	0.00000	0.00000	0.00000
TO-BUS	25		23.85070 MW	3.66018 MVAR		
TO-BUS	29		6.24249 MW	1.77657 MVAR		
TO-BUS	30		7.15912 MW	1.79474 MVAR		
TO-BUS	28		-37.25544 MW	-7.22862 MVAR		
28	0.8814	-19.78	0.00000	0.00000	0.00000	0.00000
TO-BUS	6		-33.91822 MW	-9.16527 MVAR		
TO-BUS	8		-3.34678 MW	-5.75779 MVAR		
TO-BUS	27		37.25544 MW	14.92080 MVAR		
26	0.8016	-34.97	0.00000	0.00000	3.50000	2.30000
TO-BUS	25		-3.49870 MW	-2.29958 MVAR		
24	0.8760	-29.01	0.00000	0.00000	8.70000	6.70000
TO-BUS	25		21.72317 MW	2.43597 MVAR		
TO-BUS	23		-10.76604 MW	-2.82661 MVAR		
TO-BUS	22		-19.65928 MW	-3.00846 MVAR		
25	0.8236	-34.33	0.00000	0.00000	40.00000	0.00000
TO-BUS	26		3.56811 MW	2.40325 MVAR		
TO-BUS	27		-22.99236 MW	-2.02125 MVAR		
TO-BUS	24		-20.54938 MW	-0.38606 MVAR		

```
23  0.9014   -27.17     0.00000     0.00000     3.20000     1.60000
TO-BUS    24      10.97917 MW     3.26255 MVAR
TO-BUS    15     -14.17913 MW    -4.86230 MVAR

14  0.9398   -25.18     0.00000     0.00000     6.20000     1.60000
TO-BUS    15       3.89771 MW     1.06751 MVAR
TO-BUS    12     -10.09528 MW    -2.66756 MVAR

15  0.9284   -25.54     0.00000     0.00000     8.20000     2.50000
TO-BUS    18       7.28318 MW     2.46303 MVAR
TO-BUS    12     -26.08151 MW    -9.35321 MVAR
TO-BUS    23      14.45567 MW     5.42091 MVAR
TO-BUS    14      -3.85684 MW    -1.03059 MVAR

18  0.9143   -26.43     0.00000     0.00000     3.20000     0.90000
TO-BUS    19       4.01064 MW     1.41317 MVAR
TO-BUS    15      -7.20960 MW    -2.31318 MVAR

12  0.9606   -23.75     0.00000     0.00000    11.20000     7.50000
TO-BUS    16      11.25405 MW     6.05834 MVAR
TO-BUS    13       0.00000 MW   -23.18121 MVAR
TO-BUS     4     -59.36607 MW    -3.87212 MVAR
TO-BUS    14      10.24724 MW     2.98346 MVAR
TO-BUS    15      26.67117 MW    10.51472 MVAR

19  0.9095   -26.73     0.00000     0.00000     9.50000     3.40000
TO-BUS    20      -5.49982 MW    -2.01472 MVAR
TO-BUS    18      -3.99681 MW    -1.38522 MVAR

20  0.9131   -26.52     0.00000     0.00000     2.20000     0.70000
TO-BUS    10      -7.71322 MW    -2.74290 MVAR
TO-BUS    19       5.51393 MW     2.04293 MVAR

22  0.9087   -26.72     0.00000     0.00000     0.00000     0.00000
TO-BUS    21      -6.94885 MW     0.84791 MVAR
TO-BUS    10     -13.30399 MW    -4.77867 MVAR
TO-BUS    24      20.25206 MW     3.93113 MVAR

21  0.9093   -26.60     0.00000     0.00000    17.50000    11.20000
TO-BUS    10     -24.45111 MW   -10.36476 MVAR
TO-BUS    22       6.95574 MW    -0.83390 MVAR

10  0.9274   -25.60     0.00000     0.00000     5.80000     2.00000
TO-BUS     9     -34.00312 MW    -8.76311 MVAR
TO-BUS    17       1.45628 MW     2.05833 MVAR
TO-BUS    21      24.74793 MW    11.00361 MVAR
TO-BUS    22      13.47994 MW     5.14146 MVAR
TO-BUS     6     -19.26365 MW     1.99189 MVAR
TO-BUS    20       7.78846 MW     2.91091 MVAR

17  0.9250   -25.64     0.00000     0.00000     9.00000     5.80000
TO-BUS    10      -1.45389 MW    -2.05209 MVAR
TO-BUS    16      -7.54329 MW    -3.74720 MVAR

16  0.9371   -24.81     0.00000     0.00000     3.50000     1.80000
TO-BUS    17       7.58674 MW     3.90664 MVAR
TO-BUS    12     -11.08675 MW    -5.70657 MVAR
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 4  0.9168   -14.50     0.00000     0.00000     7.60000     1.60000
TO-BUS    12       59.36607 MW    13.69147 MVAR
TO-BUS     6      139.46028 MW    14.51818 MVAR
TO-BUS     2      -84.55691 MW   -14.74291 MVAR
TO-BUS     3     -121.89503 MW   -15.06771 MVAR

13  0.9944   -23.75     0.00000    24.00000     0.00000     0.00000
TO-BUS    12        0.00000 MW    23.99652 MVAR

 1  1.0600     0.00   336.62650    87.66045     0.00000     0.00000
TO-BUS     2      201.55470 MW    38.89213 MVAR
TO-BUS     3      135.07179 MW    48.91305 MVAR

 2  1.0059    -5.81    40.00000    50.00000    21.70000    12.70000
TO-BUS     4       89.52343 MW    26.46912 MVAR
TO-BUS     6      123.05465 MW    33.67859 MVAR   OVERLOAD
TO-BUS     1     -194.31345 MW   -22.84387 MVAR

 9  0.9386   -23.14     0.00000     0.00000     0.00000     0.00000
TO-BUS    11        0.00000 MW   -22.77218 MVAR
TO-BUS    10       34.00312 MW    10.34018 MVAR
TO-BUS     6      -34.00371 MW    12.43165 MVAR

 6  0.8941   -18.41     0.00000     0.00000     0.00000     0.00000
TO-BUS     9       34.00371 MW    -9.33703 MVAR
TO-BUS    10       19.26365 MW     0.43284 MVAR
TO-BUS     8       33.53344 MW    -7.63703 MVAR
TO-BUS     7      129.28069 MW    21.50466 MVAR   OVERLOAD
TO-BUS     2     -113.63410 MW    -8.47981 MVAR   OVERLOAD
TO-BUS    28       34.18478 MW     9.08546 MVAR
TO-BUS     4     -136.67542 MW    -5.56767 MVAR

11  0.9891   -23.14     0.00000    24.00000     0.00000     0.00000
TO-BUS     9        0.00000 MW    23.99647 MVAR

 7  0.8426   -26.05     0.00000     0.00000    22.80000    10.90000
TO-BUS     5      100.71512 MW    -5.75850 MVAR   OVERLOAD
TO-BUS     6     -123.53388 MW    -5.13824 MVAR   OVERLOAD

 5  0.8070   -36.14     0.00000    40.00000    94.20000    19.00000
TO-BUS     7      -94.12657 MW    20.98459 MVAR

 8  0.8932   -19.48     0.00000    40.00000    30.00000    30.00000
TO-BUS    28        3.36968 MW     2.46002 MVAR
TO-BUS     6      -33.35668 MW     7.53697 MVAR

 3  0.9417   -11.56     0.00000     0.00000     2.40000     1.20000
TO-BUS     4      124.26235 MW    21.13929 MVAR
TO-BUS     1     -126.67771 MW   -22.33498 MVAR



FROM AREA

              TO   AREA   MW FLOW  MVAR FLOW
```

We may observe that, with a line 2-5 outage, other lines become overloaded in their real power limits. We have two feasible options: we may add shunt capacitors to buses 6/7 to add reactive power or increase line limits. Since shunt capacitors may be expensive to add, we can instead adjust the line limits from 100[MV A] $\rightarrow$ 150[MV A]. This way, the power flow limits are met.

2.2.2 Line 2-6 Outage

Power Flow Solution - Line 2-6 Outage Case

```
Power Flow Case Title :
Base MVA :  100.0 MVA

          CONVERGENCE SUMMARY
 ITER            DELP              DELQ

  0.0          0.933447
  0.5                            0.840789
  1.0          0.128867
  1.5                            0.042609
  2.0          0.016523
  2.5                            0.004612
  3.0          0.002454
  3.5                            0.340734
  4.0          0.070224
  4.5                            0.026829
  5.0          0.005224
  5.5                            0.062296
  6.0          0.020730
  6.5                            0.006717
  7.0          0.004189
  7.5                            0.001390
  8.0          0.001460
  8.5                            0.000451
  9.0          0.000519


BUS   VOLTAGE   ANGLE        GENERATION               LOAD
NO.    PU      DEG       MW        MVAR        MW        MVAR


  30  0.9001   -30.52     0.00000     0.00000    10.60000     1.90000
  TO-BUS    29       -3.66638 MW    -0.54563 MVAR
  TO-BUS    27       -6.92151 MW    -1.35518 MVAR

  29  0.9128   -29.45     0.00000     0.00000     2.40000     0.90000
  TO-BUS    27       -6.10611 MW    -1.52232 MVAR
  TO-BUS    30        3.70706 MW     0.62249 MVAR

  27  0.9348   -27.97     0.00000     0.00000     0.00000     0.00000
  TO-BUS    25       23.82980 MW     3.27425 MVAR
  TO-BUS    29        6.21057 MW     1.71970 MVAR
  TO-BUS    30        7.11809 MW     1.72519 MVAR
  TO-BUS    28      -37.16875 MW    -6.71328 MVAR
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28  0.9448   -18.69     0.00000     0.00000     0.00000     0.00000
TO-BUS     6     -33.87814 MW    -7.54016 MVAR
TO-BUS     8      -3.31404 MW    -5.64161 MVAR
TO-BUS    27      37.16875 MW    13.17857 MVAR

26  0.8809   -31.65     0.00000     0.00000     3.50000     2.30000
TO-BUS    25      -3.49847 MW    -2.29920 MVAR

24  0.9483   -26.67     0.00000     0.00000     8.70000     6.70000
TO-BUS    25      21.36476 MW     2.18796 MVAR
TO-BUS    23     -10.56499 MW    -2.26540 MVAR
TO-BUS    22     -19.51093 MW    -2.75284 MVAR

25  0.9009   -31.11     0.00000     0.00000    40.00000     0.00000
TO-BUS    26       3.55593 MW     2.38502 MVAR
TO-BUS    27     -23.10606 MW    -1.89233 MVAR
TO-BUS    24     -20.39794 MW    -0.49948 MVAR

23  0.9698   -25.08     0.00000     0.00000     3.20000     1.60000
TO-BUS    24      10.73637 MW     2.61593 MVAR
TO-BUS    15     -13.93728 MW    -4.21543 MVAR

14  1.0033   -23.33     0.00000     0.00000     6.20000     1.60000
TO-BUS    15       3.77143 MW     0.84278 MVAR
TO-BUS    12      -9.96777 MW    -2.44281 MVAR

15  0.9933   -23.65     0.00000     0.00000     8.20000     2.50000
TO-BUS    18       7.17517 MW     2.09150 MVAR
TO-BUS    12     -25.79977 MW    -8.44879 MVAR
TO-BUS    23      14.16269 MW     4.67077 MVAR
TO-BUS    14      -3.73864 MW    -0.81315 MVAR

18  0.9810   -24.44     0.00000     0.00000     3.20000     0.90000
TO-BUS    19       3.91587 MW     1.06778 MVAR
TO-BUS    15      -7.11442 MW    -1.96780 MVAR

12  1.0220   -22.07     0.00000     0.00000    11.20000     7.50000
TO-BUS    16      11.09773 MW     5.21310 MVAR
TO-BUS    13       0.00000 MW   -23.26914 MVAR
TO-BUS     4     -58.67933 MW    -1.57231 MVAR
TO-BUS    14      10.09659 MW     2.71059 MVAR
TO-BUS    15      26.29429 MW     9.42288 MVAR

19  0.9771   -24.70     0.00000     0.00000     9.50000     3.40000
TO-BUS    20      -5.59034 MW    -2.35424 MVAR
TO-BUS    18      -3.90493 MW    -1.04566 MVAR

20  0.9807   -24.52     0.00000     0.00000     2.20000     0.70000
TO-BUS    10      -7.80255 MW    -3.08040 MVAR
TO-BUS    19       5.60345 MW     2.38045 MVAR

22  0.9777   -24.70     0.00000     0.00000     0.00000     0.00000
TO-BUS    21      -6.80301 MW     1.09594 MVAR
TO-BUS    10     -13.20670 MW    -4.62080 MVAR
TO-BUS    24      20.00744 MW     3.52566 MVAR

21  0.9783   -24.60     0.00000     0.00000    17.50000    11.20000
```

```
TO-BUS    10     -24.30387 MW   -10.11366 MVAR
TO-BUS    22       6.80878 MW    -1.08422 MVAR

10  0.9948   -23.74     0.00000     0.00000     5.80000     2.00000
TO-BUS     9     -33.89652 MW    -7.43783 MVAR
TO-BUS    17       1.57285 MW     2.80597 MVAR
TO-BUS    21      24.55585 MW    10.65600 MVAR
TO-BUS    22      13.35558 MW     4.92778 MVAR
TO-BUS     6     -19.24716 MW     2.62116 MVAR
TO-BUS    20       7.87104 MW     3.23332 MVAR

17  0.9919   -23.76     0.00000     0.00000     9.00000     5.80000
TO-BUS    10      -1.56947 MW    -2.79713 MVAR
TO-BUS    16      -7.42727 MW    -3.00176 MVAR

16  1.0017   -23.03     0.00000     0.00000     3.50000     1.80000
TO-BUS    17       7.46145 MW     3.12720 MVAR
TO-BUS    12     -10.96170 MW    -4.92709 MVAR

 4  0.9659   -13.92     0.00000     0.00000     7.60000     1.60000
TO-BUS    12      58.67933 MW    10.01831 MVAR
TO-BUS     6     135.37600 MW   -10.63397 MVAR
TO-BUS     2     -83.62999 MW    -4.06979 MVAR
TO-BUS     3    -118.05976 MW     3.08441 MVAR

13  1.0538   -22.07     0.00000    24.00000     0.00000     0.00000
TO-BUS    12       0.00000 MW    23.99494 MVAR

 1  1.0600     0.00   315.40325    22.96943     0.00000     0.00000
TO-BUS     2     185.91537 MW    -1.26663 MVAR
TO-BUS     3     129.48789 MW    24.42279 MVAR

 2  1.0303    -5.60    40.00000    50.00000    21.70000    12.70000
TO-BUS     4      87.90634 MW    13.43147 MVAR
TO-BUS     5     110.36018 MW    10.68412 MVAR   OVERLOAD
TO-BUS     1    -180.00851 MW    13.18761 MVAR

 9  1.0037   -21.60     0.00000     0.00000     0.00000     0.00000
TO-BUS    11       0.00000 MW   -22.91149 MVAR
TO-BUS    10      33.89652 MW     8.77651 MVAR
TO-BUS     6     -33.89761 MW    14.13456 MVAR

 6  0.9554   -17.47     0.00000     0.00000     0.00000     0.00000
TO-BUS     9      33.89761 MW   -11.34964 MVAR
TO-BUS    10      19.24716 MW    -0.50115 MVAR
TO-BUS     8      33.46835 MW    -8.43606 MVAR
TO-BUS     7      12.29195 MW    -4.86737 MVAR
TO-BUS    28      34.10463 MW     7.16937 MVAR
TO-BUS     4    -133.02514 MW    17.98196 MVAR

11  1.0512   -21.60     0.00000    24.00000     0.00000     0.00000
TO-BUS     9       0.00000 MW    23.99532 MVAR

 7  0.9556   -18.17     0.00000     0.00000    22.80000    10.90000
TO-BUS     5     -10.55140 MW   -14.36501 MVAR
TO-BUS     6     -12.24286 MW     3.46600 MVAR

 5  0.9770   -17.80     0.00000    40.00000    94.20000    19.00000
```

```
  TO-BUS     7      10.69839 MW    12.83064 MVAR
  TO-BUS     2    -104.87086 MW     8.16438 MVAR   OVERLOAD

   8  0.9549   -18.42     0.00000    40.00000    30.00000    30.00000
  TO-BUS    28       3.33179 MW     1.83599 MVAR
  TO-BUS     6     -33.31264 MW     8.15993 MVAR

   3  0.9818   -11.18     0.00000     0.00000     2.40000     1.20000
  TO-BUS     4     120.03348 MW     1.78586 MVAR
  TO-BUS     1    -122.45574 MW    -2.97975 MVAR



FROM AREA

              TO   AREA   MW FLOW  MVAR FLOW
```

We may observe that no contingency correction is needed, as all lines continued to operate despite a loss between lines 2 and 6. Thus, we may leave the system alone.

2.2.3 Line 15-23 Outage

Power Flow Solution - Line 15-23 Outage Case

```
Power Flow Case Title :
Base MVA :  100.0 MVA

          CONVERGENCE SUMMARY
 ITER            DELP              DELQ

  0.0          0.933447
  0.5                            0.822618
  1.0          0.170181
  1.5                            0.046542
  2.0          0.013035
  2.5                            0.002342
  3.0          0.001560
  3.5                            0.185750
  4.0          0.080727
  4.5                            0.020630
  5.0          0.003444
  5.5                            0.014395
  6.0          0.004591
  6.5                            0.001247
  7.0          0.000561
  7.5                            0.000200


BUS   VOLTAGE   ANGLE        GENERATION              LOAD
NO.    PU     DEG      MW        MVAR        MW        MVAR


  30  0.9242   -26.77     0.00000     0.00000    10.60000     1.90000
```

```
TO-BUS    29      -3.66959 MW    -0.54297 MVAR
TO-BUS    27      -6.92736 MW    -1.35297 MVAR

29  0.9365   -25.75     0.00000     0.00000     2.40000     0.90000
TO-BUS    27      -6.10814 MW    -1.51538 MVAR
TO-BUS    30       3.70824 MW     0.61600 MVAR

27  0.9579   -24.35     0.00000     0.00000     0.00000     0.00000
TO-BUS    25      27.54650 MW     4.77663 MVAR
TO-BUS    29       6.20740 MW     1.70292 MVAR
TO-BUS    30       7.11413 MW     1.70451 MVAR
TO-BUS    28     -40.87850 MW    -8.18904 MVAR

28  0.9738   -14.67     0.00000     0.00000     0.00000     0.00000
TO-BUS     6     -36.82592 MW    -9.46000 MVAR
TO-BUS     8      -4.05444 MW    -6.23291 MVAR
TO-BUS    27      40.87850 MW    15.69079 MVAR

26  0.8980   -28.27     0.00000     0.00000     3.50000     2.30000
TO-BUS    25      -3.49975 MW    -2.29897 MVAR

24  0.9522   -24.02     0.00000     0.00000     8.70000     6.70000
TO-BUS    25      17.56534 MW     0.48414 MVAR
TO-BUS    23       3.21869 MW     1.63814 MVAR
TO-BUS    22     -29.48825 MW    -4.92391 MVAR

25  0.9177   -27.75     0.00000     0.00000    40.00000     0.00000
TO-BUS    26       3.55507 MW     2.38160 MVAR
TO-BUS    27     -26.61537 MW    -2.99871 MVAR
TO-BUS    24     -16.92333 MW     0.63708 MVAR

23  0.9431   -24.44     0.00000     0.00000     3.20000     1.60000
TO-BUS    24      -3.19970 MW    -1.59929 MVAR

14  1.0352   -18.66     0.00000     0.00000     6.20000     1.60000
TO-BUS    15       1.44780 MW     0.29235 MVAR
TO-BUS    12      -7.64681 MW    -1.89109 MVAR

15  1.0315   -18.78     0.00000     0.00000     8.20000     2.50000
TO-BUS    18      10.65476 MW     2.69858 MVAR
TO-BUS    12     -17.41240 MW    -4.91140 MVAR
TO-BUS    14      -1.44330 MW    -0.28828 MVAR

18  1.0149   -19.90     0.00000     0.00000     3.20000     0.90000
TO-BUS    19       7.33287 MW     1.55040 MVAR
TO-BUS    15     -10.53293 MW    -2.45051 MVAR

12  1.0491   -17.75     0.00000     0.00000    11.20000     7.50000
TO-BUS    16      13.41799 MW     5.01789 MVAR
TO-BUS    13       0.00000 MW   -16.35722 MVAR
TO-BUS     4     -49.95237 MW    -3.51160 MVAR
TO-BUS    14       7.71809 MW     2.03927 MVAR
TO-BUS    15      17.61605 MW     5.31253 MVAR

19  1.0084   -20.37     0.00000     0.00000     9.50000     3.40000
TO-BUS    20      -2.20190 MW    -1.91985 MVAR
TO-BUS    18      -7.29802 MW    -1.47994 MVAR
```

```
20  1.0104   -20.32     0.00000     0.00000     2.20000     0.70000
TO-BUS    10      -4.40479 MW    -2.62565 MVAR
TO-BUS    19       2.20475 MW     1.92556 MVAR

22  0.9983   -21.18     0.00000     0.00000     0.00000     0.00000
TO-BUS    21     -13.21504 MW    -0.85644 MVAR
TO-BUS    10     -17.41078 MW    -5.83405 MVAR
TO-BUS    24      30.62203 MW     6.68866 MVAR   OVERLOAD

21  1.0000   -21.00     0.00000     0.00000    17.50000    11.20000
TO-BUS    10     -30.73688 MW   -12.09975 MVAR
TO-BUS    22      13.23546 MW     0.89797 MVAR

10  1.0199   -19.95     0.00000     0.00000     5.80000     2.00000
TO-BUS     9     -37.18384 MW    -8.97758 MVAR
TO-BUS    17      -0.68708 MW     3.14954 MVAR
TO-BUS    21      31.11661 MW    12.91704 MVAR
TO-BUS    22      17.65677 MW     6.34125 MVAR
TO-BUS     6     -21.13038 MW     1.65921 MVAR
TO-BUS    20       4.42890 MW     2.67949 MVAR

17  1.0175   -19.86     0.00000     0.00000     9.00000     5.80000
TO-BUS    10       0.69031 MW    -3.14110 MVAR
TO-BUS    16      -9.69066 MW    -2.65960 MVAR

16  1.0277   -18.91     0.00000     0.00000     3.50000     1.80000
TO-BUS    17       9.74176 MW     2.84715 MVAR
TO-BUS    12     -13.24178 MW    -4.64737 MVAR

 4  0.9922   -11.18     0.00000     0.00000     7.60000     1.60000
TO-BUS    12      49.95237 MW     9.34448 MVAR
TO-BUS     6      91.05951 MW    -9.50893 MVAR
TO-BUS     2     -51.59127 MW    -5.04978 MVAR
TO-BUS     3     -97.01904 MW     3.61835 MVAR

13  1.0709   -17.75     0.00000    16.69758     0.00000     0.00000
TO-BUS    12       0.00000 MW    16.69758 MVAR

 1  1.0600     0.00   310.86511     5.13018     0.00000     0.00000
TO-BUS     2     205.64988 MW    -7.50271 MVAR
TO-BUS     3     105.22836 MW    12.63289 MVAR

 2  1.0314    -6.26    40.00000    50.00000    21.70000    12.70000
TO-BUS     4      53.13829 MW     5.99537 MVAR
TO-BUS     5      89.19511 MW     3.29182 MVAR
TO-BUS     6      74.38567 MW     4.63370 MVAR
TO-BUS     1    -198.41956 MW    23.38158 MVAR

 9  1.0304   -17.72     0.00000     0.00000     0.00000     0.00000
TO-BUS    11       0.00000 MW   -22.97244 MVAR
TO-BUS    10      37.18384 MW    10.52486 MVAR
TO-BUS     6     -37.18385 MW    12.44768 MVAR

 6  0.9859   -13.45     0.00000     0.00000     0.00000     0.00000
TO-BUS     9      37.18385 MW    -9.43537 MVAR
TO-BUS    10      21.13038 MW     0.74196 MVAR
TO-BUS     8      34.22826 MW    -8.14575 MVAR
TO-BUS     7      31.76392 MW    -5.22759 MVAR
```

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 TO-BUS     2     -71.33939 MW     0.80334 MVAR
 TO-BUS    28      37.08153 MW     9.11779 MVAR
 TO-BUS     4     -90.04736 MW    12.14974 MVAR

 11  1.0768   -17.72     0.00000    24.00000     0.00000     0.00000
 TO-BUS     9       0.00000 MW    24.00633 MVAR

  7  0.9813   -15.06     0.00000     0.00000    22.80000    10.90000
 TO-BUS     5       8.68128 MW   -15.35014 MVAR
 TO-BUS     6     -31.48144 MW     4.45041 MVAR

  5  0.9944   -16.04     0.00000    40.00000    94.20000    19.00000
 TO-BUS     7      -8.54667 MW    13.69873 MVAR
 TO-BUS     2     -85.65133 MW     7.30687 MVAR

  8  0.9851   -14.35     0.00000    40.00000    30.00000    30.00000
 TO-BUS    28       4.07731 MW     2.19861 MVAR
 TO-BUS     6     -34.07628 MW     7.80358 MVAR

  3  1.0043    -9.03     0.00000     0.00000     2.40000     1.20000
 TO-BUS     4      98.28319 MW    -0.82585 MVAR
 TO-BUS     1    -100.68432 MW    -0.37481 MVAR



FROM AREA

              TO   AREA   MW FLOW  MVAR FLOW
```

We may observe that no contingency correction is needed, as all lines continued to operate despite a loss between lines 15 and 23. Thus, we may leave the system alone.

2.2.4 Line 18-19 Outage

Power Flow Solution - Line 18-19 Outage Case

```
Power Flow Case Title :
Base MVA :  100.0 MVA

          CONVERGENCE SUMMARY
 ITER            DELP              DELQ

  0.0          0.933447
  0.5                            0.831353
  1.0          0.175252
  1.5                            0.045852
  2.0          0.010772
  2.5                            0.001929
  3.0          0.001199
  3.5                            0.158022
  4.0          0.055566
  4.5                            0.014165
```

```
  5.0          0.002071
  5.5                           0.088279
  6.0          0.021184
  6.5                           0.007990
  7.0          0.001009
  7.5                           0.000320
  8.0          0.000128


BUS   VOLTAGE   ANGLE        GENERATION               LOAD
NO.    PU      DEG       MW        MVAR        MW        MVAR


  30  0.9406   -25.63     0.00000     0.00000    10.60000     1.90000
  TO-BUS    29       -3.66942 MW    -0.54403 MVAR
  TO-BUS    27       -6.92764 MW    -1.35612 MVAR

  29  0.9528   -24.65     0.00000     0.00000     2.40000     0.90000
  TO-BUS    27       -6.10680 MW    -1.51446 MVAR
  TO-BUS    30        3.70673 MW     0.61453 MVAR

  27  0.9737   -23.29     0.00000     0.00000     0.00000     0.00000
  TO-BUS    25       24.59033 MW     3.22437 MVAR
  TO-BUS    29        6.20265 MW     1.69557 MVAR
  TO-BUS    30        7.10797 MW     1.69556 MVAR
  TO-BUS    28      -37.90508 MW    -6.61391 MVAR

  28  0.9800   -14.53     0.00000     0.00000     0.00000     0.00000
  TO-BUS     6      -34.46345 MW    -7.10124 MVAR
  TO-BUS     8       -3.44820 MW    -5.69686 MVAR
  TO-BUS    27       37.90508 MW    12.79758 MVAR

  26  0.9213   -26.78     0.00000     0.00000     3.50000     2.30000
  TO-BUS    25       -3.49995 MW    -2.29980 MVAR

  24  0.9840   -22.33     0.00000     0.00000     8.70000     6.70000
  TO-BUS    25       20.48261 MW     1.94838 MVAR
  TO-BUS    23      -10.31129 MW    -1.79165 MVAR
  TO-BUS    22      -18.87659 MW    -2.69217 MVAR

  25  0.9405   -26.28     0.00000     0.00000    40.00000     0.00000
  TO-BUS    26        3.55252 MW     2.37832 MVAR
  TO-BUS    27      -23.88127 MW    -1.87047 MVAR
  TO-BUS    24      -19.65848 MW    -0.50911 MVAR

  23  1.0031   -20.85     0.00000     0.00000     3.20000     1.60000
  TO-BUS    24       10.46061 MW     2.09708 MVAR
  TO-BUS    15      -13.66134 MW    -3.69692 MVAR

  14  1.0316   -19.29     0.00000     0.00000     6.20000     1.60000
  TO-BUS    15        2.83444 MW     0.59499 MVAR
  TO-BUS    12       -9.03366 MW    -2.19498 MVAR

  15  1.0244   -19.52     0.00000     0.00000     8.20000     2.50000
  TO-BUS    18        3.21129 MW     0.92325 MVAR
  TO-BUS    12      -22.45566 MW    -6.94293 MVAR
  TO-BUS    23       13.86041 MW     4.09904 MVAR
  TO-BUS    14       -2.81702 MW    -0.57925 MVAR
```

```
18  1.0191   -19.85     0.00000     0.00000     3.20000     0.90000
TO-BUS    15      -3.19987 MW    -0.90000 MVAR

12  1.0481   -18.20     0.00000     0.00000    11.20000     7.50000
TO-BUS    16      10.30078 MW     4.13585 MVAR
TO-BUS    13       0.00000 MW   -17.09900 MVAR
TO-BUS     4     -53.43404 MW    -4.56862 MVAR
TO-BUS    14       9.13362 MW     2.40278 MVAR
TO-BUS    15      22.80415 MW     7.62939 MVAR

19  1.0023   -21.12     0.00000     0.00000     9.50000     3.40000
TO-BUS    20      -9.49950 MW    -3.39999 MVAR

20  1.0079   -20.82     0.00000     0.00000     2.20000     0.70000
TO-BUS    10     -11.73402 MW    -4.16887 MVAR
TO-BUS    19       9.53395 MW     3.46889 MVAR

22  1.0114   -20.57     0.00000     0.00000     0.00000     0.00000
TO-BUS    21      -6.37846 MW     1.19705 MVAR
TO-BUS    10     -12.93075 MW    -4.56113 MVAR
TO-BUS    24      19.30839 MW     3.36429 MVAR

21  1.0119   -20.47     0.00000     0.00000    17.50000    11.20000
TO-BUS    10     -23.88316 MW   -10.01240 MVAR
TO-BUS    22       6.38323 MW    -1.18733 MVAR

10  1.0276   -19.68     0.00000     0.00000     5.80000     2.00000
TO-BUS     9     -36.45855 MW    -7.77127 MVAR
TO-BUS    17       2.33567 MW     3.79189 MVAR
TO-BUS    21      24.11109 MW    10.50297 MVAR
TO-BUS    22      13.06436 MW     4.83661 MVAR
TO-BUS     6     -20.72692 MW     2.21675 MVAR
TO-BUS    20      11.87690 MW     4.48791 MVAR

17  1.0238   -19.72     0.00000     0.00000     9.00000     5.80000
TO-BUS    10      -2.32959 MW    -3.77602 MVAR
TO-BUS    16      -6.66999 MW    -2.02386 MVAR

16  1.0311   -19.08     0.00000     0.00000     3.50000     1.80000
TO-BUS    17       6.69428 MW     2.11300 MVAR
TO-BUS    12     -10.19478 MW    -3.91297 MVAR

 4  0.9947   -11.18     0.00000     0.00000     7.60000     1.60000
TO-BUS    12      53.43404 MW    11.27160 MVAR
TO-BUS     6      87.69843 MW   -13.01839 MVAR
TO-BUS     2     -51.75863 MW    -4.57959 MVAR
TO-BUS     3     -96.97493 MW     4.72608 MVAR

13  1.0709   -18.20     0.00000    17.45722     0.00000     0.00000
TO-BUS    12       0.00000 MW    17.47165 MVAR

 1  1.0600     0.00   309.96587     1.16749     0.00000     0.00000
TO-BUS     2     204.80686 MW   -10.20091 MVAR
TO-BUS     3     105.15901 MW    11.42277 MVAR

 2  1.0330    -6.25    40.00000    50.00000    21.70000    12.70000
TO-BUS     4      53.30647 MW     5.51273 MVAR
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```
TO-BUS     5      88.84895 MW     2.59688 MVAR
TO-BUS     6      73.76298 MW     3.28070 MVAR
TO-BUS     1    -197.63024 MW    25.91019 MVAR

 9  1.0367   -17.52     0.00000     0.00000     0.00000     0.00000
TO-BUS    11       0.00000 MW   -22.63783 MVAR
TO-BUS    10      36.45855 MW     9.21877 MVAR
TO-BUS     6     -36.45860 MW    13.41900 MVAR

 6  0.9901   -13.38     0.00000     0.00000     0.00000     0.00000
TO-BUS     9      36.45860 MW   -10.49788 MVAR
TO-BUS    10      20.72692 MW     0.07103 MVAR
TO-BUS     8      33.60889 MW    -8.77003 MVAR
TO-BUS     7      32.06367 MW    -4.75349 MVAR
TO-BUS     2     -70.78514 MW     1.92674 MVAR
TO-BUS    28      34.67982 MW     6.60662 MVAR
TO-BUS     4     -86.75432 MW    15.41655 MVAR

11  1.0821   -17.52     0.00000    23.61750     0.00000     0.00000
TO-BUS     9       0.00000 MW    23.62967 MVAR

 7  0.9851   -14.99     0.00000     0.00000    22.80000    10.90000
TO-BUS     5       8.98303 MW   -14.86782 MVAR
TO-BUS     6     -31.77949 MW     3.96808 MVAR

 5  0.9974   -15.97     0.00000    40.00000    94.20000    19.00000
TO-BUS     7      -8.85349 MW    13.18991 MVAR
TO-BUS     2     -85.34661 MW     7.80816 MVAR

 8  0.9897   -14.26     0.00000    40.00000    30.00000    30.00000
TO-BUS    28       3.46485 MW     1.59770 MVAR
TO-BUS     6     -33.46214 MW     8.40173 MVAR

 3  1.0063    -9.04     0.00000     0.00000     2.40000     1.20000
TO-BUS     4      98.23318 MW    -1.95421 MVAR
TO-BUS     1    -100.63478 MW     0.75488 MVAR



FROM AREA

             TO   AREA   MW FLOW  MVAR FLOW
```

We may observe that no contingency correction is needed, as all lines continued to operate despite a loss between lines 18 and 19. Thus, we may leave the system alone.

2.2.5 Line 22-24 Outage

```
_____________________ Power Flow Solution - Line 22-24 Outage Case _____________________

Power Flow Case Title :
Base MVA :  100.0 MVA
```

CONVERGENCE SUMMARY

ITER	DELP	DELQ
0.0	0.933447	
0.5		0.837755
1.0	0.181568	
1.5		0.048109
2.0	0.013455	
2.5		0.003444
3.0	0.002102	
3.5		0.182917
4.0	0.059553	
4.5		0.014926
5.0	0.002666	
5.5		0.100932
6.0	0.024275	
6.5		0.009095
7.0	0.001289	
7.5		0.000427
8.0	0.000345	

BUS NO.	VOLTAGE PU	ANGLE DEG	GENERATION MW	GENERATION MVAR	LOAD MW	LOAD MVAR
30	0.9161	-28.06	0.00000	0.00000	10.60000	1.90000
TO-BUS	29		-3.66813 MW	-0.54491 MVAR		
TO-BUS	27		-6.92495 MW	-1.35547 MVAR		
29	0.9286	-27.03	0.00000	0.00000	2.40000	0.90000
TO-BUS	27		-6.10720 MW	-1.51906 MVAR		
TO-BUS	30		3.70744 MW	0.61919 MVAR		
27	0.9501	-25.60	0.00000	0.00000	0.00000	0.00000
TO-BUS	25		32.19897 MW	5.59536 MVAR		
TO-BUS	29		6.20817 MW	1.70983 MVAR		
TO-BUS	30		7.11492 MW	1.71305 MVAR		
TO-BUS	28		-45.53526 MW	-9.01383 MVAR		
28	0.9736	-14.72	0.00000	0.00000	0.00000	0.00000
TO-BUS	6		-40.55741 MW	-11.70540 MVAR		
TO-BUS	8		-4.99858 MW	-6.76223 MVAR		
TO-BUS	27		45.53526 MW	18.46614 MVAR		
26	0.8831	-30.22	0.00000	0.00000	3.50000	2.30000
TO-BUS	25		-3.49928 MW	-2.29950 MVAR		
24	0.9279	-26.75	0.00000	0.00000	8.70000	6.70000
TO-BUS	25		12.98539 MW	-0.09273 MVAR		
TO-BUS	23		-21.69269 MW	-2.90266 MVAR		
25	0.9031	-29.68	0.00000	0.00000	40.00000	0.00000
TO-BUS	26		3.55648 MW	2.38494 MVAR		
TO-BUS	27		-30.90573 MW	-3.12601 MVAR		
TO-BUS	24		-12.61623 MW	0.73743 MVAR		

```
23  0.9690   -23.26     0.00000     0.00000     3.20000     1.60000
TO-BUS    24      22.42699 MW     4.40465 MVAR
TO-BUS    15     -25.63455 MW    -6.00344 MVAR

14  1.0221   -20.15     0.00000     0.00000     6.20000     1.60000
TO-BUS    15       5.01923 MW     1.11718 MVAR
TO-BUS    12     -11.21657 MW    -2.71713 MVAR

15  1.0091   -20.57     0.00000     0.00000     8.20000     2.50000
TO-BUS    18       0.68950 MW     1.31053 MVAR
TO-BUS    12     -30.30441 MW   -10.23777 MVAR
TO-BUS    23      26.37273 MW     7.49457 MVAR
TO-BUS    14      -4.96329 MW    -1.06664 MVAR

18  1.0055   -20.58     0.00000     0.00000     3.20000     0.90000
TO-BUS    19      -2.51249 MW     0.40582 MVAR
TO-BUS    15      -0.68719 MW    -1.30583 MVAR

12  1.0427   -18.79     0.00000     0.00000    11.20000     7.50000
TO-BUS    16       3.45599 MW     3.95458 MVAR
TO-BUS    13       0.00000 MW   -20.98716 MVAR
TO-BUS     4     -56.98833 MW    -5.05779 MVAR
TO-BUS    14      11.37352 MW     3.04339 MVAR
TO-BUS    15      30.96958 MW    11.54800 MVAR

19  1.0066   -20.38     0.00000     0.00000     9.50000     3.40000
TO-BUS    20     -12.01595 MW    -3.00242 MVAR
TO-BUS    18       2.51659 MW    -0.39754 MVAR

20  1.0127   -19.98     0.00000     0.00000     2.20000     0.70000
TO-BUS    10     -14.26764 MW    -3.80530 MVAR
TO-BUS    19      12.06742 MW     3.10537 MVAR

22  1.0255   -18.84     0.00000     0.00000     0.00000     0.00000
TO-BUS    21       5.29111 MW     3.30253 MVAR
TO-BUS    10      -5.29111 MW    -3.30253 MVAR

21  1.0241   -18.89     0.00000     0.00000    17.50000    11.20000
TO-BUS    10     -12.21258 MW    -7.90594 MVAR
TO-BUS    22      -5.28682 MW    -3.29380 MVAR

10  1.0341   -18.54     0.00000     0.00000     5.80000     2.00000
TO-BUS     9     -29.93156 MW    -4.64658 MVAR
TO-BUS    17       9.09917 MW     3.78037 MVAR
TO-BUS    21      12.28281 MW     8.05708 MVAR
TO-BUS    22       5.31800 MW     3.35798 MVAR
TO-BUS     6     -17.03321 MW     3.51974 MVAR
TO-BUS    20      14.46663 MW     4.24963 MVAR

17  1.0282   -18.89     0.00000     0.00000     9.00000     5.80000
TO-BUS    10      -9.06975 MW    -3.70365 MVAR
TO-BUS    16       0.07032 MW    -2.09621 MVAR

16  1.0321   -18.96     0.00000     0.00000     3.50000     1.80000
TO-BUS    17      -0.06814 MW     2.10421 MVAR
TO-BUS    12      -3.43201 MW    -3.90417 MVAR

 4  0.9920   -11.24     0.00000     0.00000     7.60000     1.60000
```

```
TO-BUS    12      56.98833 MW    12.76474 MVAR
TO-BUS     6      85.19900 MW   -12.95375 MVAR
TO-BUS     2     -52.28576 MW    -5.16226 MVAR
TO-BUS     3     -97.50396 MW     3.75074 MVAR

13  1.0709   -18.79     0.00000    21.52253     0.00000     0.00000
TO-BUS    12       0.00000 MW    21.55431 MVAR

 1  1.0600     0.00   311.22059     4.35230     0.00000     0.00000
TO-BUS     2     205.44431 MW    -8.27767 MVAR
TO-BUS     3     105.77628 MW    12.71194 MVAR

 2  1.0318    -6.25    40.00000    50.00000    21.70000    12.70000
TO-BUS     4      53.87578 MW     6.23803 MVAR
TO-BUS     5      88.87788 MW     2.95218 MVAR
TO-BUS     6      73.75627 MW     3.99608 MVAR
TO-BUS     1    -198.22713 MW    24.11471 MVAR

 9  1.0395   -16.79     0.00000     0.00000     0.00000     0.00000
TO-BUS    11       0.00000 MW   -21.27811 MVAR
TO-BUS    10      29.93156 MW     5.59037 MVAR
TO-BUS     6     -29.93121 MW    15.68767 MVAR

 6  0.9877   -13.39     0.00000     0.00000     0.00000     0.00000
TO-BUS     9      29.93121 MW   -13.48955 MVAR
TO-BUS    10      17.03321 MW    -1.94682 MVAR
TO-BUS     8      35.18407 MW    -7.57017 MVAR
TO-BUS     7      32.04851 MW    -5.01455 MVAR
TO-BUS     2     -70.76796 MW     1.25663 MVAR
TO-BUS    28      40.87263 MW    11.57246 MVAR
TO-BUS     4     -84.30228 MW    15.19163 MVAR

11  1.0821   -16.79     0.00000    22.13188     0.00000     0.00000
TO-BUS     9       0.00000 MW    22.14959 MVAR

 7  0.9829   -15.00     0.00000     0.00000    22.80000    10.90000
TO-BUS     5       8.96710 MW   -15.14189 MVAR
TO-BUS     6     -31.76260 MW     4.24224 MVAR

 5  0.9956   -16.00     0.00000    40.00000    94.20000    19.00000
TO-BUS     7      -8.83339 MW    13.48271 MVAR
TO-BUS     2     -85.36388 MW     7.51453 MVAR

 8  0.9866   -14.31     0.00000    40.00000    30.00000    30.00000
TO-BUS    28       5.03038 MW     2.75095 MVAR
TO-BUS     6     -35.02554 MW     7.24803 MVAR

 3  1.0041    -9.08     0.00000     0.00000     2.40000     1.20000
TO-BUS     4      98.78154 MW    -0.91928 MVAR
TO-BUS     1    -101.18478 MW    -0.27948 MVAR



FROM AREA

              TO   AREA   MW FLOW  MVAR FLOW
```

We may observe that no contingency correction is needed, as all lines continued to operate despite a loss between lines 22 and 24. We may note that this is because, despite a line limit of 30[MVA], the shunt capacitor at bus 24 is injecting reactice power to compensate for line overloading. Thus, we may leave the system alone.

2.2.6 Loss of Synchronous Condeneser (Bus 8)

Power Flow Solution - Loss of Bus 8 Synchronous Condenser

```
Power Flow Case Title :
Base MVA :  100.0 MVA

          CONVERGENCE SUMMARY
 ITER            DELP              DELQ

  0.0          0.933447
  0.5                            0.833367
  1.0          0.106775
  1.5                            0.039631
  2.0          0.011378
  2.5                            0.001808
  3.0          0.001684
  3.5                            0.254522
  4.0          0.112572
  4.5                            0.032010
  5.0          0.001802
  5.5                            0.012396
  6.0          0.003699
  6.5                            0.001052
  7.0          0.000304
  7.5                            0.000116


BUS   VOLTAGE   ANGLE        GENERATION               LOAD
NO.    PU      DEG       MW        MVAR        MW        MVAR


  30  0.9320   -25.76     0.00000     0.00000    10.60000     1.90000
  TO-BUS    29       -3.67005 MW    -0.54333 MVAR
  TO-BUS    27       -6.92827 MW    -1.35429 MVAR

  29  0.9443   -24.76     0.00000     0.00000     2.40000     0.90000
  TO-BUS    27       -6.10804 MW    -1.51484 MVAR
  TO-BUS    30        3.70806 MW     0.61515 MVAR

  27  0.9654   -23.38     0.00000     0.00000     0.00000     0.00000
  TO-BUS    25       24.47157 MW     2.98559 MVAR
  TO-BUS    29        6.20567 MW     1.69930 MVAR
  TO-BUS    30        7.11196 MW     1.70005 MVAR
  TO-BUS    28      -37.79453 MW    -6.38848 MVAR

  28  0.9716   -14.49     0.00000     0.00000     0.00000     0.00000
  TO-BUS     6      -34.41482 MW    -8.36616 MVAR
  TO-BUS     8       -3.38066 MW    -4.26620 MVAR
  TO-BUS    27       37.79453 MW    12.63080 MVAR
```

```
26  0.9132   -26.92     0.00000     0.00000     3.50000     2.30000
TO-BUS    25      -3.49999 MW    -2.29960 MVAR

24  0.9776   -22.41     0.00000     0.00000     8.70000     6.70000
TO-BUS    25      20.63581 MW     2.22718 MVAR
TO-BUS    23      -9.50533 MW    -2.12335 MVAR
TO-BUS    22     -19.83287 MW    -2.69459 MVAR

25  0.9326   -26.42     0.00000     0.00000    40.00000     0.00000
TO-BUS    26       3.55349 MW     2.37951 MVAR
TO-BUS    27     -23.75885 MW    -1.62471 MVAR
TO-BUS    24     -19.78611 MW    -0.74325 MVAR

23  0.9966   -21.07     0.00000     0.00000     3.20000     1.60000
TO-BUS    24       9.63635 MW     2.39135 MVAR
TO-BUS    15     -12.83668 MW    -3.99164 MVAR

14  1.0265   -19.56     0.00000     0.00000     6.20000     1.60000
TO-BUS    15       3.31534 MW     0.79464 MVAR
TO-BUS    12      -9.51406 MW    -2.39310 MVAR

15  1.0178   -19.83     0.00000     0.00000     8.20000     2.50000
TO-BUS    18       6.19779 MW     1.91021 MVAR
TO-BUS    12     -24.12686 MW    -7.99845 MVAR
TO-BUS    23      13.01864 MW     4.35920 MVAR
TO-BUS    14      -3.29096 MW    -0.77261 MVAR

18  1.0072   -20.47     0.00000     0.00000     3.20000     0.90000
TO-BUS    19       2.95427 MW     0.92155 MVAR
TO-BUS    15      -6.15422 MW    -1.82149 MVAR

12  1.0440   -18.42     0.00000     0.00000    11.20000     7.50000
TO-BUS    16       9.28344 MW     4.59854 MVAR
TO-BUS    13       0.00000 MW   -20.03388 MVAR
TO-BUS     4     -54.64973 MW    -3.50249 MVAR
TO-BUS    14       9.62651 MW     2.62686 MVAR
TO-BUS    15      24.53975 MW     8.81177 MVAR

19  1.0042   -20.65     0.00000     0.00000     9.50000     3.40000
TO-BUS    20      -6.55175 MW    -2.49059 MVAR
TO-BUS    18      -2.94824 MW    -0.90935 MVAR

20  1.0081   -20.45     0.00000     0.00000     2.20000     0.70000
TO-BUS    10      -8.76846 MW    -3.22392 MVAR
TO-BUS    19       6.56831 MW     2.52373 MVAR

22  1.0064   -20.52     0.00000     0.00000     0.00000     0.00000
TO-BUS    21      -6.98686 MW     1.14461 MVAR
TO-BUS    10     -13.32947 MW    -4.59045 MVAR
TO-BUS    24      20.31492 MW     3.44492 MVAR

21  1.0069   -20.42     0.00000     0.00000    17.50000    11.20000
TO-BUS    10     -24.49383 MW   -10.06956 MVAR
TO-BUS    22       6.99260 MW    -1.13293 MVAR

10  1.0230   -19.60     0.00000     0.00000     5.80000     2.00000
TO-BUS     9     -35.82911 MW    -7.05391 MVAR
```

```
TO-BUS    17       3.33608 MW     3.28707 MVAR
TO-BUS    21      24.73454 MW    10.58764 MVAR
TO-BUS    22      13.47212 MW     4.88459 MVAR
TO-BUS     6     -20.36111 MW     2.77844 MVAR
TO-BUS    20       8.84885 MW     3.40342 MVAR

17  1.0192   -19.69     0.00000     0.00000     9.00000     5.80000
TO-BUS    10      -3.32929 MW    -3.26936 MVAR
TO-BUS    16      -5.67098 MW    -2.53160 MVAR

16  1.0270   -19.17     0.00000     0.00000     3.50000     1.80000
TO-BUS    17       5.69044 MW     2.60299 MVAR
TO-BUS    12      -9.19039 MW    -4.40288 MVAR

 4  0.9890   -11.16     0.00000     0.00000     7.60000     1.60000
TO-BUS    12      54.64973 MW    10.54561 MVAR
TO-BUS     6      86.64482 MW    -8.29018 MVAR
TO-BUS     2     -51.89328 MW    -5.93159 MVAR
TO-BUS     3     -97.00037 MW     2.07864 MVAR

13  1.0709   -18.42     0.00000    20.54938     0.00000     0.00000
TO-BUS    12       0.00000 MW    20.54938 MVAR

 1  1.0600     0.00   310.18710     9.42040     0.00000     0.00000
TO-BUS     2     204.96288 MW    -4.86653 MVAR
TO-BUS     3     105.23777 MW    14.28693 MVAR

 2  1.0300    -6.22    40.00000    50.00000    21.70000    12.70000
TO-BUS     4      53.47264 MW     6.99297 MVAR
TO-BUS     5      88.93069 MW     3.84464 MVAR
TO-BUS     6      73.68026 MW     5.86538 MVAR
TO-BUS     1    -197.78366 MW    20.59993 MVAR

 9  1.0313   -17.46     0.00000     0.00000     0.00000     0.00000
TO-BUS    11       0.00000 MW   -22.97418 MVAR
TO-BUS    10      35.82911 MW     8.45551 MVAR
TO-BUS     6     -35.82917 MW    14.51852 MVAR

 6  0.9825   -13.33     0.00000     0.00000     0.00000     0.00000
TO-BUS     9      35.82917 MW   -11.59581 MVAR
TO-BUS    10      20.36111 MW    -0.53489 MVAR
TO-BUS     8      33.53113 MW    -0.14458 MVAR
TO-BUS     7      32.03926 MW    -5.72522 MVAR
TO-BUS     2     -70.67323 MW    -0.52975 MVAR
TO-BUS    28      34.63763 MW     7.91484 MVAR
TO-BUS     4     -85.72390 MW    10.61952 MVAR

11  1.0776   -17.46     0.00000    24.00000     0.00000     0.00000
TO-BUS     9       0.00000 MW    24.00638 MVAR

 7  0.9783   -14.98     0.00000     0.00000    22.80000    10.90000
TO-BUS     5       8.94850 MW   -15.88357 MVAR
TO-BUS     6     -31.74869 MW     4.98350 MVAR

 5  0.9919   -15.99     0.00000    40.00000    94.20000    19.00000
TO-BUS     7      -8.80321 MW    14.27008 MVAR
TO-BUS     2     -85.39547 MW     6.73421 MVAR
```

```
 8  0.9784   -14.17     0.00000     0.00000    30.00000     0.00000
TO-BUS    28        3.39176 MW     0.23249 MVAR
TO-BUS     6      -33.39135 MW    -0.23142 MVAR

 3  1.0017    -9.01     0.00000     0.00000     2.40000     1.20000
TO-BUS     4       98.27108 MW     0.73767 MVAR
TO-BUS     1     -100.67197 MW    -1.93845 MVAR



FROM AREA

              TO   AREA   MW FLOW  MVAR FLOW
```

The loss of a synchronous condensor means that the bus is unable to adjust the reactive power system as needed. To ensure that the bus is within its reactive limit, we may modify bus 8 such that it is switched from a PV bus to a PQ bus.

3 Conclusion

We may observe that outages occurred for only two cases: the outage of line 2/5 and the loss of the synchronous condenser at bus 8. The former resulted in outages due to increased real power flow. We adjusted for this by increasing the line limit from $100 \rightarrow 150[\text{MV A}]$ (alternatively, we could have added shunt capacitance to buses 6/7. The latter resulted in an inability to adjust for reactive power, and, thus, we changed it from a PV to a PQ bus.