Lab Six (Part A)
Power Systems Analysis
EECE5682

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Abstract

This laboratory experiment allows the user to explore power flow solutions to a real-life instance of a 30-bus system. Furthermore, by performing the experiment, the individual will develop a better understanding of total transfer capability (TTC) between buses, and how this can be improved.

KEYWORDS: power flow, 30-bus system, total transfer capability

1 Introduction & Objectives

We begin by constructing the provided 30-bus system 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 base 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                           0.811045
  1.0          0.177421
  1.5                           0.043765
  2.0          0.004835
  2.5                           0.001707
  3.0          0.000512
  3.5                           0.000106


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


  30  0.9919   -17.65     0.00000     0.00000    10.60000     1.90000
  TO-BUS    29      -3.67070 MW    -0.54329 MVAR
  TO-BUS    27      -6.93014 MW    -1.35811 MVAR

  29  1.0033   -16.77     0.00000     0.00000     2.40000     0.90000
  TO-BUS    27      -6.10366 MW    -1.50593 MVAR
  TO-BUS    30       3.70427 MW     0.60673 MVAR

  27  1.0232   -15.54     0.00000     0.00000     0.00000     0.00000
  TO-BUS    25       4.77937 MW     0.40768 MVAR
  TO-BUS    29       6.18996 MW     1.66898 MVAR
  TO-BUS    30       7.09246 MW     1.66364 MVAR
  TO-BUS    28     -18.06277 MW    -3.74554 MVAR

  28  1.0067   -11.69     0.00000     0.00000     0.00000     0.00000
  TO-BUS     6     -18.60722 MW    -1.09960 MVAR
  TO-BUS     8       0.54468 MW    -3.93080 MVAR
  TO-BUS    27      18.06277 MW     5.03274 MVAR
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26  0.9996   -16.49     0.00000     0.00000     3.50000     2.30000
TO-BUS    25      -3.49779 MW    -2.29712 MVAR

24  1.0215   -16.49     0.00000     0.00000     8.70000     6.70000
TO-BUS    25      -1.20283 MW     2.01842 MVAR
TO-BUS    23      -1.80049 MW    -1.23247 MVAR
TO-BUS    22      -5.69465 MW    -2.99514 MVAR

25  1.0173   -16.07     0.00000     0.00000     0.00000     0.00000
TO-BUS    26       3.54237 MW     2.36372 MVAR
TO-BUS    27      -4.75535 MW    -0.36181 MVAR
TO-BUS    24       1.21281 MW    -2.00100 MVAR

23  1.0271   -16.32     0.00000     0.00000     3.20000     1.60000
TO-BUS    24       1.80651 MW     1.24479 MVAR
TO-BUS    15      -5.00630 MW    -2.84421 MVAR

14  1.0422   -15.84     0.00000     0.00000     6.20000     1.60000
TO-BUS    15       1.58218 MW     0.64405 MVAR
TO-BUS    12      -7.78446 MW    -2.24554 MVAR

15  1.0376   -15.93     0.00000     0.00000     8.20000     2.50000
TO-BUS    18       6.01829 MW     1.59309 MVAR
TO-BUS    12     -17.67674 MW    -6.35815 MVAR
TO-BUS    23       5.03772 MW     2.90768 MVAR
TO-BUS    14      -1.57624 MW    -0.63869 MVAR

18  1.0281   -16.54     0.00000     0.00000     3.20000     0.90000
TO-BUS    19       2.77973 MW     0.61464 MVAR
TO-BUS    15      -5.97966 MW    -1.51443 MVAR

12  1.0570   -14.94     0.00000     0.00000    11.20000     7.50000
TO-BUS    16       7.24699 MW     3.34507 MVAR
TO-BUS    13       0.00000 MW   -10.46410 MVAR
TO-BUS     4     -44.20123 MW    -9.57718 MVAR
TO-BUS    14       7.85885 MW     2.40018 MVAR
TO-BUS    15      17.89373 MW     6.78556 MVAR

19  1.0256   -16.72     0.00000     0.00000     9.50000     3.40000
TO-BUS    20      -6.72510 MW    -2.79512 MVAR
TO-BUS    18      -2.77483 MW    -0.60473 MVAR

20  1.0297   -16.52     0.00000     0.00000     2.20000     0.70000
TO-BUS    10      -8.94192 MW    -3.52870 MVAR
TO-BUS    19       6.74224 MW     2.82940 MVAR

22  1.0332   -16.13     0.00000     0.00000     0.00000     0.00000
TO-BUS    21       1.82528 MW     1.42679 MVAR
TO-BUS    10      -7.56634 MW    -4.49345 MVAR
TO-BUS    24       5.74027 MW     3.06616 MVAR

21  1.0327   -16.14     0.00000     0.00000    17.50000    11.20000
TO-BUS    10     -15.67544 MW    -9.77459 MVAR
TO-BUS    22      -1.82470 MW    -1.42560 MVAR

10  1.0451   -15.70     0.00000     0.00000     5.80000     2.00000
TO-BUS     9     -27.72001 MW    -5.13676 MVAR
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TO-BUS    17       5.32891 MW     4.43450 MVAR
TO-BUS    21      15.78680 MW    10.01427 MVAR
TO-BUS    22       7.61907 MW     4.60219 MVAR
TO-BUS     6     -15.83730 MW     1.12662 MVAR
TO-BUS    20       9.02350 MW     3.71086 MVAR

17  1.0399   -15.86     0.00000     0.00000     9.00000     5.80000
TO-BUS    10      -5.31465 MW    -4.39732 MVAR
TO-BUS    16      -3.68608 MW    -1.40479 MVAR

16  1.0443   -15.53     0.00000     0.00000     3.50000     1.80000
TO-BUS    17       3.69363 MW     1.43246 MVAR
TO-BUS    12      -7.19311 MW    -3.23177 MVAR

 4  1.0117    -9.28     0.00000     0.00000     7.60000     1.60000
TO-BUS    12      44.20123 MW    14.26369 MVAR
TO-BUS     6      72.15240 MW   -16.28534 MVAR
TO-BUS     2     -42.60653 MW    -4.75421 MVAR
TO-BUS     3     -81.34577 MW     5.18646 MVAR

13  1.0709   -14.94     0.00000    10.60130     0.00000     0.00000
TO-BUS    12       0.00000 MW    10.60130 MVAR

 1  1.0600     0.00   260.80431   -16.69576     0.00000     0.00000
TO-BUS     2     173.21857 MW   -21.27109 MVAR
TO-BUS     3      87.72038 MW     4.57533 MVAR

 2  1.0431    -5.35    40.00000    49.99921    21.70000    12.70000
TO-BUS     4      43.62203 MW     3.96345 MVAR
TO-BUS     5      82.38047 MW     1.85454 MVAR
TO-BUS     6      60.33773 MW     0.52259 MVAR
TO-BUS     1    -168.03414 MW    30.95862 MVAR

 9  1.0509   -14.11     0.00000     0.00000     0.00000     0.00000
TO-BUS    11       0.00000 MW   -15.76347 MVAR
TO-BUS    10      27.72001 MW     5.93721 MVAR
TO-BUS     6     -27.72032 MW     9.82536 MVAR

 6  1.0102   -11.06     0.00000     0.00000     0.00000     0.00000
TO-BUS     9      27.72032 MW    -8.19631 MVAR
TO-BUS    10      15.83730 MW     0.15666 MVAR
TO-BUS     8      29.56520 MW    -8.00825 MVAR
TO-BUS     7      38.12058 MW    -2.94581 MVAR
TO-BUS     2     -58.39021 MW     1.44404 MVAR
TO-BUS    28      18.66499 MW    -0.01777 MVAR
TO-BUS     4     -71.51803 MW    17.57247 MVAR

11  1.0821   -14.11     0.00000    16.23147     0.00000     0.00000
TO-BUS     9       0.00000 MW    16.23147 MVAR

 7  1.0023   -12.86     0.00000     0.00000    22.80000    10.90000
TO-BUS     5      14.93886 MW   -13.29609 MVAR
TO-BUS     6     -37.73924 MW     2.39566 MVAR

 5  1.0099   -14.17     0.00000    36.80215    94.20000    19.00000
TO-BUS     7     -14.76772 MW    11.66269 MVAR
TO-BUS     2     -79.42907 MW     6.13946 MVAR
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```
  8  1.0099   -11.81     0.00000    37.05927    30.00000    30.00000
 TO-BUS    28       -0.54255 MW    -0.41402 MVAR
 TO-BUS     6      -29.45571 MW     7.47329 MVAR

  3  1.0207    -7.53     0.00000     0.00000     2.40000     1.20000
 TO-BUS     4       82.20320 MW    -3.59207 MVAR
 TO-BUS     1      -84.60593 MW     2.39010 MVAR



FROM AREA

              TO   AREA   MW FLOW  MVAR FLOW
```

2.2 Part 2

We may determine the total transfer capability (TTC) from the source (bus 1) to the sink (bus 25) by slowly increasing the real power load of the sink. Taking steps of 5[MW], we begin increasing from 0. We may observe that the solution diverges when we change the real load to 80[MW]. We reduce by 1[MW] until we get a real solution. This occurs at $P_L = 75$[MW]. As such, we have determined that the TTC is 75[MW].

2.3 Part 3

Using the result from Part 2, we run a simulation with $P_L = 75$[MW] for the sink. This gives us the following data:

```
_____________________ Power Flow Solution - TTC Case _____________________

 Power Flow Case Title :
 Base MVA :  100.0 MVA

          CONVERGENCE SUMMARY
  ITER            DELP              DELQ

   0.0          0.933447
   0.5                            0.850784
   1.0          0.166959
   1.5                            0.057378
   2.0          0.037550
   2.5                            0.013455
   3.0          0.012255
   3.5                            0.004786
   4.0          0.004013
   4.5                            0.411415
   5.0          0.192231
   5.5                            0.043739
   6.0          0.024446
   6.5                            0.008644
```

7.0	0.011624		
7.5		0.004114	
8.0	0.005583		
8.5		0.130599	
9.0	0.064698		
9.5		0.015000	
10.0	0.038978		
10.5		0.012291	
11.0	0.028702		
11.5		0.008878	
12.0	0.021744		
12.5		0.006742	
13.0	0.016907		
13.5		0.005224	
14.0	0.013454		
14.5		0.004142	
15.0	0.010909		
15.5		0.003348	
16.0	0.008980		
16.5		0.002749	
17.0	0.007484		
17.5		0.002286	
18.0	0.006301		
18.5		0.001921	
19.0	0.005351		
19.5		0.001629	
20.0	0.004578		
20.5		0.001392	
21.0	0.003941		
21.5		0.001196	
22.0	0.003410		
22.5		0.001034	
23.0	0.002965		
23.5		0.000898	
24.0	0.002588		
24.5		0.000784	
25.0	0.002267		
25.5		0.000686	
26.0	0.001991		
26.5		0.000602	
27.0	0.001754		
27.5		0.000530	
28.0	0.001549		
28.5		0.000468	
29.0	0.001370		
29.5		0.000414	
30.0	0.001215		
30.5		0.000367	
31.0	0.001079		
31.5		0.000325	
32.0	0.000959		

BUS NO.	VOLTAGE PU	ANGLE DEG	GENERATION MW	GENERATION MVAR	LOAD MW	LOAD MVAR
30	0.7390	-40.47	0.00000	0.00000	10.60000	1.90000

```
TO-BUS    29      -3.66920 MW    -0.55317 MVAR
TO-BUS    27      -6.91881 MW    -1.34773 MVAR

29  0.7546   -38.90     0.00000     0.00000     2.40000     0.90000
TO-BUS    27      -6.12798 MW    -1.56735 MVAR
TO-BUS    30       3.72968 MW     0.66746 MVAR

27  0.7816   -36.76     0.00000     0.00000     0.00000     0.00000
TO-BUS    25      43.84764 MW    11.04109 MVAR
TO-BUS    29       6.28243 MW     1.85916 MVAR
TO-BUS    30       7.21014 MW     1.89609 MVAR
TO-BUS    28     -57.36310 MW   -14.78829 MVAR

28  0.8755   -18.02     0.00000     0.00000     0.00000     0.00000
TO-BUS     6     -49.91967 MW   -27.42527 MVAR
TO-BUS     8      -7.48720 MW   -10.11672 MVAR
TO-BUS    27      57.36310 MW    37.53596 MVAR

26  0.6719   -46.04     0.00000     0.00000     3.50000     2.30000
TO-BUS    25      -3.49658 MW    -2.29909 MVAR

24  0.8154   -32.02     0.00000     0.00000     8.70000     6.70000
TO-BUS    25      43.99399 MW     8.33144 MVAR
TO-BUS    23     -17.61500 MW    -5.10734 MVAR
TO-BUS    22     -35.10510 MW    -7.06075 MVAR   OVERLOAD

25  0.6982   -45.13     0.00000     0.00000    75.00000     0.00000
TO-BUS    26       3.59526 MW     2.44649 MVAR
TO-BUS    27     -40.18964 MW    -4.05643 MVAR
TO-BUS    24     -38.30972 MW     1.59568 MVAR

23  0.8623   -28.69     0.00000     0.00000     3.20000     1.60000
TO-BUS    24      18.28283 MW     6.47336 MVAR
TO-BUS    15     -21.48514 MW    -8.07258 MVAR

14  0.9236   -25.61     0.00000     0.00000     6.20000     1.60000
TO-BUS    15       5.44622 MW     1.63653 MVAR
TO-BUS    12     -11.64236 MW    -3.23656 MVAR

15  0.9070   -26.10     0.00000     0.00000     8.20000     2.50000
TO-BUS    18       6.40397 MW     1.93897 MVAR
TO-BUS    12     -31.43700 MW   -12.38138 MVAR
TO-BUS    23      22.19365 MW     9.50376 MVAR
TO-BUS    14      -5.36243 MW    -1.56081 MVAR

18  0.8949   -26.95     0.00000     0.00000     3.20000     0.90000
TO-BUS    19       3.14696 MW     0.92003 MVAR
TO-BUS    15      -6.34558 MW    -1.82007 MVAR

12  0.9485   -23.92     0.00000     0.00000    11.20000     7.50000
TO-BUS    16      11.64192 MW     6.43489 MVAR
TO-BUS    13       0.00000 MW   -23.16084 MVAR
TO-BUS     4     -67.04120 MW    -8.63510 MVAR
TO-BUS    14      11.85310 MW     3.67464 MVAR
TO-BUS    15      32.35560 MW    14.19084 MVAR

19  0.8913   -27.19     0.00000     0.00000     9.50000     3.40000
TO-BUS    20      -6.35741 MW    -2.49724 MVAR
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```
TO-BUS    18      -3.13838 MW    -0.90269 MVAR

20  0.8956   -26.95     0.00000     0.00000     2.20000     0.70000
TO-BUS    10      -8.57647 MW    -3.23714 MVAR
TO-BUS    19       6.37738 MW     2.53718 MVAR

22  0.8830   -27.66     0.00000     0.00000     0.00000     0.00000
TO-BUS    21     -17.26284 MW    -3.20128 MVAR
TO-BUS    10     -20.06321 MW    -7.31008 MVAR
TO-BUS    24      37.32297 MW    10.51291 MVAR   OVERLOAD

21  0.8861   -27.39     0.00000     0.00000    17.50000    11.20000
TO-BUS    10     -34.80287 MW   -14.49265 MVAR
TO-BUS    22      17.30871 MW     3.29459 MVAR

10  0.9123   -25.90     0.00000     0.00000     5.80000     2.00000
TO-BUS     9     -45.63141 MW   -14.21960 MVAR
TO-BUS    17       1.09203 MW     1.74255 MVAR
TO-BUS    21      35.43282 MW    15.84849 MVAR
TO-BUS    22      20.48841 MW     8.18681 MVAR
TO-BUS     6     -25.84503 MW    -1.19560 MVAR
TO-BUS    20       8.67452 MW     3.45608 MVAR

17  0.9103   -25.93     0.00000     0.00000     9.00000     5.80000
TO-BUS    10      -1.09038 MW    -1.73826 MVAR
TO-BUS    16      -7.90590 MW    -4.06084 MVAR

16  0.9236   -25.03     0.00000     0.00000     3.50000     1.80000
TO-BUS    17       7.95586 MW     4.24415 MVAR
TO-BUS    12     -11.45604 MW    -6.04405 MVAR

 4  0.9213   -13.37     0.00000     0.00000     7.60000     1.60000
TO-BUS    12      67.04120 MW    21.63782 MVAR
TO-BUS     6     101.91616 MW    10.98334 MVAR
TO-BUS     2     -62.48403 MW   -16.40024 MVAR
TO-BUS     3    -114.09893 MW   -17.82308 MVAR

13  0.9826   -23.92     0.00000    24.00000     0.00000     0.00000
TO-BUS    12       0.00000 MW    23.99567 MVAR

 1  1.0600     0.00   370.41258    98.24316     0.00000     0.00000
TO-BUS     2     244.47068 MW    51.38912 MVAR
TO-BUS     3     125.94190 MW    47.01454 MVAR

 2  0.9938    -7.10    40.00000    50.00000    21.70000    12.70000
TO-BUS     4      65.25405 MW    21.46246 MVAR
TO-BUS     5      97.21984 MW    15.05851 MVAR
TO-BUS     6      89.54161 MW    25.64868 MVAR
TO-BUS     1    -233.75306 MW   -24.86598 MVAR

 9  0.9311   -22.51     0.00000     0.00000     0.00000     0.00000
TO-BUS    11       0.00000 MW   -22.75358 MVAR
TO-BUS    10      45.63141 MW    17.23873 MVAR
TO-BUS     6     -45.63548 MW     5.51415 MVAR

 6  0.9041   -16.18     0.00000     0.00000     0.00000     0.00000
TO-BUS     9      45.63548 MW    -0.44441 MVAR
TO-BUS    10      25.84503 MW     5.66727 MVAR
```

```
 TO-BUS     8      37.79223 MW    -2.91751 MVAR
 TO-BUS     7      24.88939 MW   -11.24936 MVAR
 TO-BUS     2     -84.38075 MW   -13.36391 MVAR
 TO-BUS    28      50.62890 MW    28.90949 MVAR
 TO-BUS     4    -100.44166 MW    -6.60330 MVAR

 11  0.9819   -22.51     0.00000    24.00000     0.00000     0.00000
 TO-BUS     9       0.00000 MW    23.99576 MVAR

  7  0.9067   -17.81     0.00000     0.00000    22.80000    10.90000
 TO-BUS     5       1.85598 MW   -21.48861 MVAR
 TO-BUS     6     -24.65063 MW    10.58917 MVAR

  5  0.9322   -18.60     0.00000    40.00000    94.20000    19.00000
 TO-BUS     7      -1.61543 MW    20.37034 MVAR
 TO-BUS     2     -92.56310 MW     0.62506 MVAR

  8  0.9004   -17.32     0.00000    40.00000    30.00000    30.00000
 TO-BUS    28       7.59332 MW     7.07494 MVAR
 TO-BUS     6     -37.58158 MW     2.92214 MVAR

  3  0.9458   -10.68     0.00000     0.00000     2.40000     1.20000
 TO-BUS     4     116.17117 MW    23.04074 MVAR
 TO-BUS     1    -118.58322 MW   -24.23665 MVAR



FROM AREA

              TO   AREA   MW FLOW  MVAR FLOW
```

2.4 Part 4

With the added shunt capacitor at bus 26, we now have a new TTC solution. We repeat the process outline in Part 2 to obtain a new TTC solution of $P_L = 82$[MW]. Running the power flow solution gets us:

Power Flow Solution - TTC Case w/Added Capacitor

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

          CONVERGENCE SUMMARY
  ITER            DELP              DELQ

   0.0          0.933447
   0.5                            0.854042
   1.0          0.182262
   1.5                            0.059693
   2.0          0.042819
   2.5                            0.019586
   3.0          0.016513
```

3.5		0.006292
4.0	0.005925	
4.5		0.369528
5.0	0.191971	
5.5		0.044315
6.0	0.024831	
6.5		0.009296
7.0	0.012399	
7.5		0.004634
8.0	0.006298	
8.5		0.106019
9.0	0.052678	
9.5		0.012038
10.0	0.033901	
10.5		0.011389
11.0	0.025984	
11.5		0.008515
12.0	0.020492	
12.5		0.006710
13.0	0.016566	
13.5		0.005404
14.0	0.013688	
14.5		0.004448
15.0	0.011516	
15.5		0.003729
16.0	0.009834	
16.5		0.003175
17.0	0.008505	
17.5		0.002738
18.0	0.007437	
18.5		0.002389
19.0	0.006565	
19.5		0.002105
20.0	0.005844	
20.5		0.001870
21.0	0.005242	
21.5		0.001674
22.0	0.004732	
22.5		0.001510
23.0	0.004299	
23.5		0.001369
24.0	0.003926	
24.5		0.001249
25.0	0.003603	
25.5		0.001145
26.0	0.003322	
26.5		0.001055
27.0	0.003076	
27.5		0.000975
28.0	0.002859	
28.5		0.000906
29.0	0.002667	
29.5		0.000844
30.0	0.002496	
30.5		0.000789
31.0	0.002343	
31.5		0.000741
32.0	0.002206	

```
 32.5                           0.000697
 33.0          0.002083
 33.5                           0.000657
 34.0          0.001972
 34.5                           0.000622
 35.0          0.001872
 35.5                           0.000590
 36.0          0.001780
 36.5                           0.000561
 37.0          0.001697
 37.5                           0.000534
 38.0          0.001621
 38.5                           0.000510
 39.0          0.001552
 39.5                           0.000488
 40.0          0.001488
 40.5                           0.000468
 41.0          0.001430
 41.5                           0.000449
 42.0          0.001377
 42.5                           0.000432
 43.0          0.001327
 43.5                           0.000417
 44.0          0.001282
 44.5                           0.000402
 45.0          0.001240
 45.5                           0.000389
 46.0          0.001201
 46.5                           0.000377
 47.0          0.001165
 47.5                           0.000365
 48.0          0.001132
 48.5                           0.000355
 49.0          0.001102
 49.5                           0.000345
 50.0          0.001073
 50.5                           0.000336
 51.0          0.001047
 51.5                           0.000328
 52.0          0.001023
 52.5                           0.000320
 53.0          0.001001
 53.5                           0.000313
 54.0          0.000980


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


  30  0.7597   -42.12     0.00000     0.00000    10.60000     1.90000
  TO-BUS    29       -3.66908 MW    -0.55194 MVAR
  TO-BUS    27       -6.91969 MW    -1.34897 MVAR

  29  0.7749   -40.63     0.00000     0.00000     2.40000     0.90000
  TO-BUS    27       -6.12460 MW    -1.55996 MVAR
  TO-BUS    30        3.72630 MW     0.66006 MVAR
```

```
27  0.8011   -38.60     0.00000     0.00000     0.00000     0.00000
TO-BUS    25      48.63893 MW     6.63922 MVAR
TO-BUS    29       6.27082 MW     1.83624 MVAR
TO-BUS    30       7.19542 MW     1.86796 MVAR
TO-BUS    28     -62.12487 MW   -10.33448 MVAR

28  0.8769   -18.78     0.00000     0.00000     0.00000     0.00000
TO-BUS     6     -53.75291 MW   -25.24034 MVAR
TO-BUS     8      -8.41567 MW    -9.57466 MVAR
TO-BUS    27      62.12487 MW    34.80806 MVAR

26  0.7600   -51.73     0.00000     0.00000     3.50000     2.30000
TO-BUS    25      -3.49721 MW     9.24957 MVAR

24  0.8267   -33.47     0.00000     0.00000     8.70000     6.70000
TO-BUS    25      47.57146 MW     3.56744 MVAR
TO-BUS    23     -18.91081 MW    -3.46900 MVAR
TO-BUS    22     -37.38495 MW    -3.85489 MVAR   OVERLOAD

25  0.7270   -47.91     0.00000     0.00000    82.00000     0.00000
TO-BUS    26       3.92794 MW    -8.60618 MVAR
TO-BUS    27     -44.53479 MW     1.19733 MVAR
TO-BUS    24     -41.29517 MW     7.39358 MVAR

23  0.8701   -29.77     0.00000     0.00000     3.20000     1.60000
TO-BUS    24      19.62470 MW     4.92922 MVAR
TO-BUS    15     -22.82706 MW    -6.52838 MVAR

14  0.9289   -26.34     0.00000     0.00000     6.20000     1.60000
TO-BUS    15       5.67623 MW     1.29580 MVAR
TO-BUS    12     -11.87230 MW    -2.89579 MVAR

15  0.9126   -26.91     0.00000     0.00000     8.20000     2.50000
TO-BUS    18       6.36979 MW     1.88816 MVAR
TO-BUS    12     -32.55396 MW   -11.20275 MVAR
TO-BUS    23      23.57166 MW     8.03248 MVAR
TO-BUS    14      -5.58940 MW    -1.21733 MVAR

18  0.9007   -27.74     0.00000     0.00000     3.20000     0.90000
TO-BUS    19       3.11430 MW     0.87232 MVAR
TO-BUS    15      -6.31292 MW    -1.77236 MVAR

12  0.9530   -24.60     0.00000     0.00000    11.20000     7.50000
TO-BUS    16      11.96358 MW     6.07466 MVAR
TO-BUS    13       0.00000 MW   -23.16816 MVAR
TO-BUS     4     -68.73510 MW    -6.79906 MVAR
TO-BUS    14      12.08537 MW     3.33873 MVAR
TO-BUS    15      33.49607 MW    13.05852 MVAR

19  0.8972   -27.98     0.00000     0.00000     9.50000     3.40000
TO-BUS    20      -6.38975 MW    -2.54427 MVAR
TO-BUS    18      -3.10606 MW    -0.85566 MVAR

20  0.9016   -27.74     0.00000     0.00000     2.20000     0.70000
TO-BUS    10      -8.60881 MW    -3.28419 MVAR
TO-BUS    19       6.40973 MW     2.58422 MVAR

22  0.8903   -28.60     0.00000     0.00000     0.00000     0.00000
```

```
TO-BUS    21     -18.74158 MW    -1.42043 MVAR
TO-BUS    10     -21.02290 MW    -6.13181 MVAR
TO-BUS    24      39.76151 MW     7.55404 MVAR   OVERLOAD

21  0.8931   -28.29     0.00000     0.00000    17.50000    11.20000
TO-BUS    10     -36.28736 MW   -12.72361 MVAR
TO-BUS    22      18.79328 MW     1.52561 MVAR

10  0.9183   -26.70     0.00000     0.00000     5.80000     2.00000
TO-BUS     9     -47.02460 MW   -12.52336 MVAR
TO-BUS    17       0.77288 MW     2.10956 MVAR
TO-BUS    21      36.93245 MW    14.11202 MVAR
TO-BUS    22      21.46275 MW     7.03873 MVAR
TO-BUS     6     -26.63813 MW    -0.21217 MVAR
TO-BUS    20       8.70656 MW     3.50247 MVAR

17  0.9161   -26.70     0.00000     0.00000     9.00000     5.80000
TO-BUS    10      -0.77094 MW    -2.10450 MVAR
TO-BUS    16      -8.22530 MW    -3.69457 MVAR

16  0.9287   -25.77     0.00000     0.00000     3.50000     1.80000
TO-BUS    17       8.27606 MW     3.88088 MVAR
TO-BUS    12     -11.77626 MW    -5.68079 MVAR

 4  0.9214   -13.84     0.00000     0.00000     7.60000     1.60000
TO-BUS    12      68.73510 MW    20.24645 MVAR
TO-BUS     6     105.34135 MW     9.24692 MVAR
TO-BUS     2     -64.34474 MW   -15.19500 MVAR
TO-BUS     3    -117.35805 MW   -15.90067 MVAR

13  0.9870   -24.60     0.00000    24.00000     0.00000     0.00000
TO-BUS    12       0.00000 MW    23.99558 MVAR

 1  1.0600     0.00   380.73923    97.53549     0.00000     0.00000
TO-BUS     2     251.05627 MW    50.92990 MVAR
TO-BUS     3     129.68296 MW    46.76868 MVAR

 2  0.9934    -7.31    40.00000    50.00000    21.70000    12.70000
TO-BUS     4      67.24907 MW    20.66765 MVAR
TO-BUS     5      98.44683 MW    14.79468 MVAR
TO-BUS     6      92.35513 MW    24.60123 MVAR
TO-BUS     1    -239.78950 MW   -22.75968 MVAR

 9  0.9350   -23.25     0.00000     0.00000     0.00000     0.00000
TO-BUS    11       0.00000 MW   -22.76284 MVAR
TO-BUS    10      47.02460 MW    15.61249 MVAR
TO-BUS     6     -47.02862 MW     7.14961 MVAR

 6  0.9047   -16.76     0.00000     0.00000     0.00000     0.00000
TO-BUS     9      47.02862 MW    -1.76578 MVAR
TO-BUS    10      26.63813 MW     4.89108 MVAR
TO-BUS     8      38.73599 MW    -3.41672 MVAR
TO-BUS     7      23.73685 MW   -10.61735 MVAR
TO-BUS     2     -86.92130 MW   -11.48845 MVAR
TO-BUS    28      54.52254 MW    26.93648 MVAR
TO-BUS     4    -103.77304 MW    -4.54114 MVAR

11  0.9856   -23.25     0.00000    24.00000     0.00000     0.00000
```

```
 TO-BUS     9       0.00000 MW    23.99566 MVAR

  7  0.9070   -18.30     0.00000     0.00000    22.80000    10.90000
 TO-BUS     5       0.72623 MW   -20.78501 MVAR
 TO-BUS     6     -23.52092 MW     9.88558 MVAR

  5  0.9322   -18.98     0.00000    40.00000    94.20000    19.00000
 TO-BUS     7      -0.50347 MW    19.62128 MVAR
 TO-BUS     2     -93.67510 MW     1.37410 MVAR

  8  0.9011   -17.92     0.00000    40.00000    30.00000    30.00000
 TO-BUS    28       8.52627 MW     6.53927 MVAR
 TO-BUS     6     -38.51462 MW     3.45777 MVAR

  3  0.9458   -11.05     0.00000     0.00000     2.40000     1.20000
 TO-BUS     4     119.53689 MW    21.42433 MVAR
 TO-BUS     1    -121.94930 MW   -22.62004 MVAR



FROM AREA

              TO   AREA   MW FLOW  MVAR FLOW
```

2.5 Part 5

Finally, we want to add 5[MW] to the TTC determined in Part 4. We may observe that the added shunt capacitance increased the TTC. Thus, we may conclude that increasing the susceptance may improve the TTC. Slowly increasing the susceptance by .01[$p.u.$], we determine that a valid way to increase the TTC by 5[MW] (from 82 $\rightarrow$ 87[MW]) is to change the susceptance from .2 $\rightarrow$ .34[$p.u.$]. This gets us the following solution:

Power Flow Solution - TTC Increased by 5

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

          CONVERGENCE SUMMARY
 ITER            DELP              DELQ

  0.0          0.933447
  0.5                            0.856323
  1.0          0.339720
  1.5                            0.172660
  2.0          0.092252
  2.5                            0.054152
  3.0          0.020796
  3.5                            0.005516
  4.0          0.008593
  4.5                            0.344067
  5.0          0.194830
```

5.5		0.045746
6.0	0.024131	
6.5		0.009338
7.0	0.012934	
7.5		0.005130
8.0	0.006810	
8.5		0.085443
9.0	0.041966	
9.5		0.010293
10.0	0.026873	
10.5		0.009472
11.0	0.021265	
11.5		0.007359
12.0	0.017014	
12.5		0.005851
13.0	0.013903	
13.5		0.004772
14.0	0.011567	
14.5		0.003956
15.0	0.009764	
15.5		0.003329
16.0	0.008344	
16.5		0.002837
17.0	0.007205	
17.5		0.002444
18.0	0.006277	
18.5		0.002125
19.0	0.005511	
19.5		0.001863
20.0	0.004873	
20.5		0.001644
21.0	0.004334	
21.5		0.001460
22.0	0.003876	
22.5		0.001304
23.0	0.003482	
23.5		0.001170
24.0	0.003143	
24.5		0.001055
25.0	0.002847	
25.5		0.000955
26.0	0.002588	
26.5		0.000867
27.0	0.002361	
27.5		0.000791
28.0	0.002159	
28.5		0.000723
29.0	0.001980	
29.5		0.000662
30.0	0.001821	
30.5		0.000608
31.0	0.001678	
31.5		0.000560
32.0	0.001549	
32.5		0.000517
33.0	0.001433	
33.5		0.000478
34.0	0.001328	

```
 34.5                          0.000443
 35.0          0.001233
 35.5                          0.000411
 36.0          0.001146
 36.5                          0.000382
 37.0          0.001067
 37.5                          0.000355
 38.0          0.000994


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


  30  0.8152   -41.89     0.00000     0.00000    10.60000     1.90000
  TO-BUS    29       -3.66827 MW    -0.54908 MVAR
  TO-BUS    27       -6.92095 MW    -1.35184 MVAR

  29  0.8292   -40.60     0.00000     0.00000     2.40000     0.90000
  TO-BUS    27       -6.11627 MW    -1.54284 MVAR
  TO-BUS    30        3.71794 MW     0.64293 MVAR

  27  0.8536   -38.81     0.00000     0.00000     0.00000     0.00000
  TO-BUS    25       53.05529 MW     0.20163 MVAR
  TO-BUS    29        6.24345 MW     1.78315 MVAR
  TO-BUS    30        7.16057 MW     1.80287 MVAR
  TO-BUS    28      -66.47597 MW    -3.77735 MVAR

  28  0.8945   -19.32     0.00000     0.00000     0.00000     0.00000
  TO-BUS     6      -57.28767 MW   -19.61567 MVAR
  TO-BUS     8       -9.23230 MW    -8.26479 MVAR
  TO-BUS    27       66.47597 MW    27.87275 MVAR

  26  0.8894   -54.49     0.00000     0.00000     3.50000     2.30000
  TO-BUS    25       -3.49749 MW    25.37905 MVAR

  24  0.8669   -33.84     0.00000     0.00000     8.70000     6.70000
  TO-BUS    25       49.96806 MW    -3.36078 MVAR
  TO-BUS    23      -19.82312 MW    -0.99145 MVAR
  TO-BUS    22      -38.86790 MW     0.88812 MVAR   OVERLOAD

  25  0.7958   -48.18     0.00000     0.00000    87.00000     0.00000
  TO-BUS    26        5.60848 MW   -22.22585 MVAR
  TO-BUS    27      -48.83256 MW     7.86135 MVAR
  TO-BUS    24      -43.67649 MW    14.34851 MVAR

  23  0.9021   -30.01     0.00000     0.00000     3.20000     1.60000
  TO-BUS    24       20.51512 MW     2.40690 MVAR
  TO-BUS    15      -23.71754 MW    -4.00599 MVAR

  14  0.9535   -26.41     0.00000     0.00000     6.20000     1.60000
  TO-BUS    15        5.75128 MW     0.73573 MVAR
  TO-BUS    12      -11.94716 MW    -2.33567 MVAR

  15  0.9387   -27.04     0.00000     0.00000     8.20000     2.50000
  TO-BUS    18        6.30917 MW     1.83675 MVAR
  TO-BUS    12      -33.27010 MW    -9.11630 MVAR
  TO-BUS    23       24.42843 MW     5.44199 MVAR
```

```
TO-BUS    14      -5.66955 MW    -0.66189 MVAR

18  0.9273   -27.82     0.00000     0.00000     3.20000     0.90000
TO-BUS    19       3.05800 MW     0.82963 MVAR
TO-BUS    15      -6.25658 MW    -1.72967 MVAR

12  0.9756   -24.70     0.00000     0.00000    11.20000     7.50000
TO-BUS    16      12.14515 MW     5.40035 MVAR
TO-BUS    13       0.00000 MW   -23.20343 MVAR
TO-BUS     4     -69.64625 MW    -3.32204 MVAR
TO-BUS    14      12.14781 MW     2.75280 MVAR
TO-BUS    15      34.16419 MW    10.87748 MVAR

19  0.9240   -28.05     0.00000     0.00000     9.50000     3.40000
TO-BUS    20      -6.44520 MW    -2.58537 MVAR
TO-BUS    18      -3.05054 MW    -0.81455 MVAR

20  0.9283   -27.81     0.00000     0.00000     2.20000     0.70000
TO-BUS    10      -8.66346 MW    -3.32375 MVAR
TO-BUS    19       6.46440 MW     2.62378 MVAR

22  0.9202   -28.76     0.00000     0.00000     0.00000     0.00000
TO-BUS    21     -19.60747 MW     1.50523 MVAR
TO-BUS    10     -21.57653 MW    -4.21551 MVAR
TO-BUS    24      41.18108 MW     2.71239 MVAR   OVERLOAD

21  0.9223   -28.44     0.00000     0.00000    17.50000    11.20000
TO-BUS    10     -37.15446 MW    -9.80043 MVAR
TO-BUS    22      19.66045 MW    -1.39745 MVAR

10  0.9446   -26.83     0.00000     0.00000     5.80000     2.00000
TO-BUS     9     -47.78162 MW    -9.18690 MVAR
TO-BUS    17       0.57691 MW     2.74886 MVAR
TO-BUS    21      37.75851 MW    11.10052 MVAR
TO-BUS    22      21.99148 MW     5.07110 MVAR
TO-BUS     6     -27.08922 MW     1.69445 MVAR
TO-BUS    20       8.75698 MW     3.53258 MVAR

17  0.9420   -26.81     0.00000     0.00000     9.00000     5.80000
TO-BUS    10      -0.57405 MW    -2.74139 MVAR
TO-BUS    16      -8.42211 MW    -3.05763 MVAR

16  0.9530   -25.87     0.00000     0.00000     3.50000     1.80000
TO-BUS    17       8.46952 MW     3.23161 MVAR
TO-BUS    12     -11.96975 MW    -5.03154 MVAR

 4  0.9331   -14.18     0.00000     0.00000     7.60000     1.60000
TO-BUS    12      69.64625 MW    16.39793 MVAR
TO-BUS     6     108.30056 MW     3.44982 MVAR
TO-BUS     2     -65.67493 MW   -11.67716 MVAR
TO-BUS     3    -119.89943 MW    -9.77308 MVAR

13  1.0089   -24.70     0.00000    24.00000     0.00000     0.00000
TO-BUS    12       0.00000 MW    23.99535 MVAR

 1  1.0600     0.00   387.39256    81.26609     0.00000     0.00000
TO-BUS     2     255.09817 MW    40.60959 MVAR
TO-BUS     3     132.29439 MW    40.83001 MVAR
```

```
 2  0.9987    -7.51    40.00000    50.00000    21.70000    12.70000
TO-BUS     4      68.56527 MW    17.04789 MVAR
TO-BUS     5      99.05410 MW    12.49606 MVAR
TO-BUS     6      94.29345 MW    19.69567 MVAR
TO-BUS     1    -243.65371 MW   -11.93535 MVAR

 9  0.9570   -23.50     0.00000     0.00000     0.00000     0.00000
TO-BUS    11       0.00000 MW   -22.81334 MVAR
TO-BUS    10      47.78162 MW    12.10526 MVAR
TO-BUS     6     -47.78541 MW    10.70732 MVAR

 6  0.9188   -17.15     0.00000     0.00000     0.00000     0.00000
TO-BUS     9      47.78541 MW    -5.26058 MVAR
TO-BUS    10      27.08922 MW     2.89566 MVAR
TO-BUS     8      39.54725 MW    -4.88825 MVAR
TO-BUS     7      23.02538 MW    -8.78630 MVAR
TO-BUS     2     -88.84356 MW    -6.60219 MVAR
TO-BUS    28      58.05784 MW    21.27665 MVAR
TO-BUS     4    -106.69537 MW     1.36298 MVAR

11  1.0066   -23.50     0.00000    24.00000     0.00000     0.00000
TO-BUS     9       0.00000 MW    23.99543 MVAR

 7  0.9196   -18.58     0.00000     0.00000    22.80000    10.90000
TO-BUS     5       0.04251 MW   -18.82759 MVAR
TO-BUS     6     -22.83710 MW     7.92821 MVAR

 5  0.9423   -19.13     0.00000    40.00000    94.20000    19.00000
TO-BUS     7       0.13306 MW    17.50217 MVAR
TO-BUS     2     -94.31046 MW     3.49301 MVAR

 8  0.9159   -18.32     0.00000    40.00000    30.00000    30.00000
TO-BUS    28       9.33417 MW     5.07775 MVAR
TO-BUS     6     -39.32204 MW     4.91915 MVAR

 3  0.9550   -11.34     0.00000     0.00000     2.40000     1.20000
TO-BUS     4     122.09247 MW    15.32103 MVAR
TO-BUS     1    -124.50574 MW   -16.51633 MVAR



FROM AREA

              TO   AREA   MW FLOW  MVAR FLOW
```

Note that we could have also added a capacitor to bus 25 itself to increase the value.