Sharif University of Technology

Electrical Energy Systems Analysis

Class Project

by:

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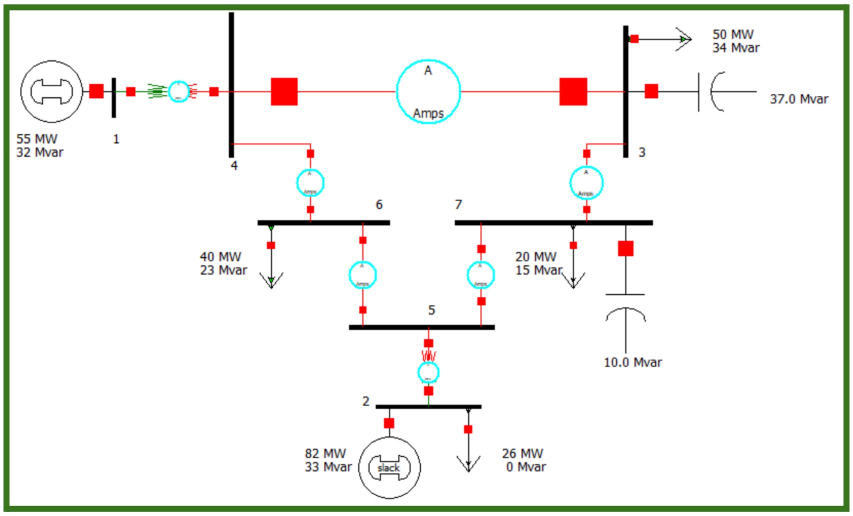
Term 1402-1

PROCEDURE:

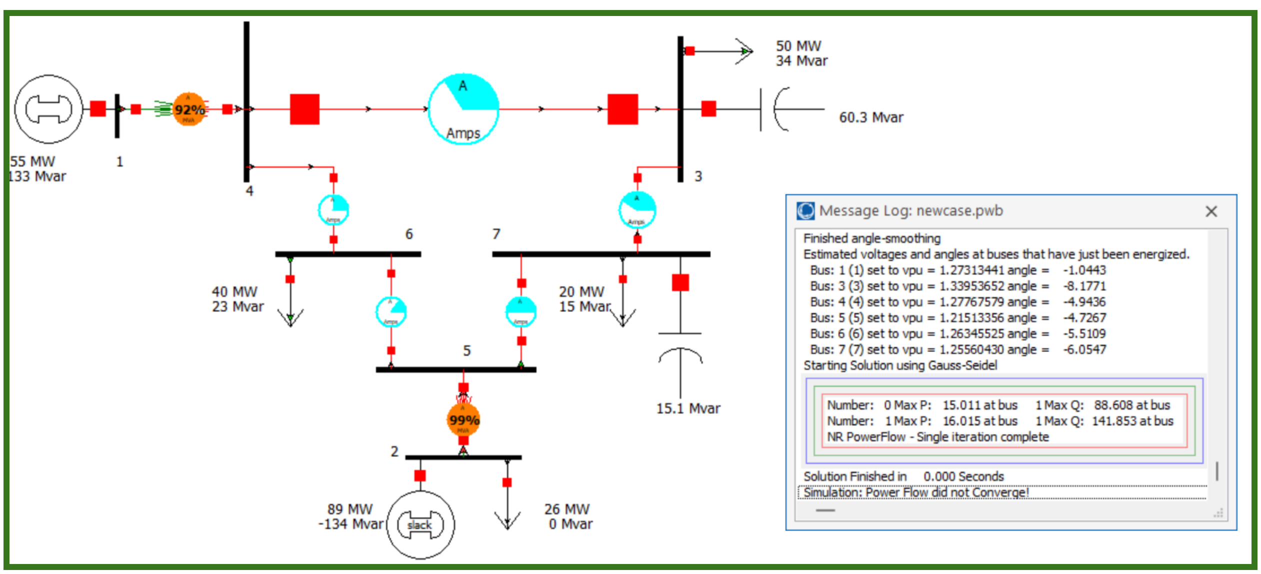
Part I: The Gauss-Seidel Method and the Newton-Raphson Method

(1) Power Flow Analysis Using Gauss-Seidel Method

The system overview:



Using only one iteration:

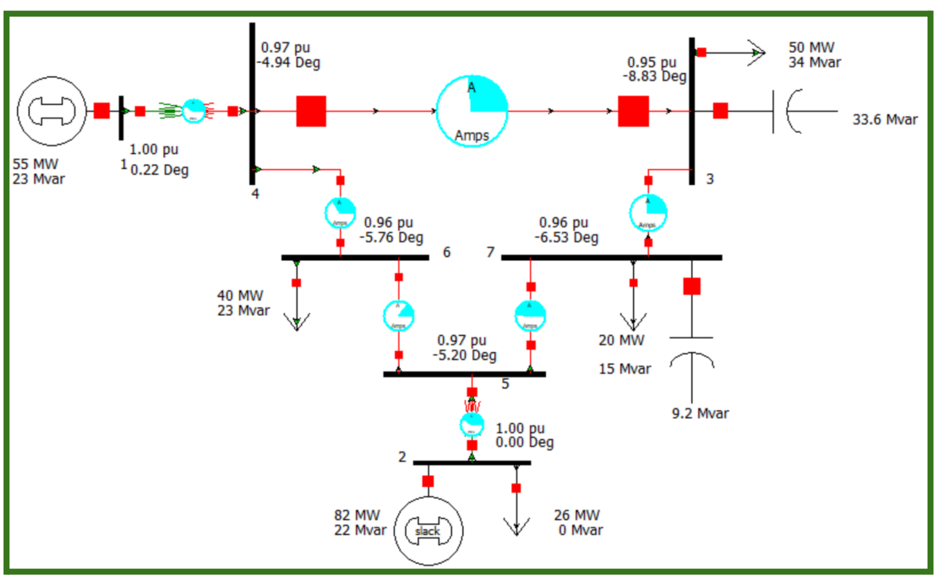


```
Bus Flows
BUS         1 1          34.5   MW     Mvar     MVA   % 1.0000   -1.88    1 1
GENERATOR 1                 55.00 -133.03L  143.9
TO         4 4        1     38.99 -133.03   138.6  92  1.0000TA   0.0
**** Mismatch *****         16.01    0.00
BUS         2 2          34.5   MW     Mvar     MVA   % 1.0000    0.00    1 1
GENERATOR 1                 89.37 -133.54R  160.7
LOAD 1                      26.00    0.00    26.0 DistGen    0.00    0.00     0.0
TO         5 5        1     63.37 -133.54   147.8  99  1.0000TA   0.0

BUS         3 3         345.0   MW     Mvar     MVA   % 1.2761   -7.44    1 1
LOAD 1                      50.00   34.00    60.5 DistGen    0.00    0.00     0.0
SWITCHED SHUNT 1             0.00   60.26    60.3
TO         4 4        1    -22.23   37.58    43.7  44
TO         7 7        1    -23.97   44.90    50.9  51
**** Mismatch *****         -3.80  -56.23
BUS         4 4         345.0   MW     Mvar     MVA   % 1.2117   -4.80    1 1
TO         1 1        1    -38.99  163.39   168.0 112  1.0000NT   0.0
TO         3 3        1     22.73  -34.68    41.5  41
TO         6 6        1     25.08   13.14    28.3  28
**** Mismatch *****         -8.82 -141.85
BUS         5 5         345.0   MW     Mvar     MVA   % 1.2151   -4.73    1 1
TO         2 2        1    -63.37  168.07   179.6 120  1.0000NT   0.0
TO         6 6        1     15.01   10.33    18.2  18
TO         7 7        1     44.59  -41.40    60.8  61
**** Mismatch *****          3.77 -137.00
BUS         6 6         345.0   MW     Mvar     MVA   % 1.2046   -5.24    1 1
LOAD 1                      40.00   23.00    46.1 DistGen    0.00    0.00     0.0
TO         4 4        1    -25.03  -12.87    28.1  28
TO         5 5        1    -14.97  -10.10    18.1  18

BUS         7 7         345.0   MW     Mvar     MVA   % 1.2291   -5.71    1 1
LOAD 1                      20.00   15.00    25.0 DistGen    0.00    0.00     0.0
SWITCHED SHUNT 1             0.00   15.11    15.1
TO         3 3        1     24.38  -42.53    49.0  49
TO         5 5        1    -44.38   42.64    61.5  62
```

Bus mismatches show how the system has not converged with only 1 iteration:

	Number	Name	Area Name	Type	Mismatch MW	Mismatch Mvar	Mismatch MVA
1	4	4	1	PQ	-8.82	-141.85	142.13
2	5	5	1	PQ	3.77	-137.00	137.05
3	3	3	1	PQ	-3.80	-56.23	56.36
4	1	1	1	PQ (Gens at Var Lim	16.01	0.00	16.01
5	6	6	1	PQ	-0.00	-0.02	0.02
6	7	7	1	PQ	0.00	-0.00	0.00
7	2	2	1	Slack	0.00	0.00	0.00

Using multiple iterations: (69 iterations until convergence)



```
Bus Flows
BUS         1 1                34.5    MW     Mvar      MVA   % 1.0000    0.22    1 1
GENERATOR 1                       55.00    22.72R    59.5
TO         4 4             1     55.03    22.72     59.5  40  1.0000TA    0.0

BUS         2 2                34.5    MW     Mvar      MVA   % 1.0000    0.00    1 1
GENERATOR 1                       81.56    22.36R    84.6
LOAD 1                            26.00     0.00     26.0 DistGen     0.00     0.00      0.0
TO         5 5             1     55.56    22.36     59.9  40  1.0000TA    0.0

BUS         3 3               345.0    MW     Mvar      MVA   % 0.9535   -8.83    1 1
LOAD 1                            50.00    34.00     60.5 DistGen     0.00     0.00      0.0
SWITCHED SHUNT 1                   0.00    33.64     33.6
TO         4 4             1    -25.32    -0.36     25.3  25
TO         7 7             1    -24.65    -0.01     24.6  25

BUS         4 4               345.0    MW     Mvar      MVA   % 0.9680   -4.94    1 1
TO         1 1             1    -55.03   -17.12     57.6  38  1.0000NT    0.0
TO         3 3             1     25.62     2.11     25.7  26
TO         6 6             1     29.48    14.99     33.1  33

BUS         5 5               345.0    MW     Mvar      MVA   % 0.9687   -5.20    1 1
TO         2 2             1    -55.56   -16.69     58.0  39  1.0000NT    0.0
TO         6 6             1     10.65     8.79     13.8  14
TO         7 7             1     45.01     7.88     45.7  46

BUS         6 6               345.0    MW     Mvar      MVA   % 0.9578   -5.76    1 1
LOAD 1                            40.00    23.00     46.1 DistGen     0.00     0.00      0.0
TO         4 4             1    -29.38   -14.41     32.7  33
TO         5 5             1    -10.62    -8.59     13.7  14

BUS         7 7               345.0    MW     Mvar      MVA   % 0.9609   -6.53    1 1
LOAD 1                            20.00    15.00     25.0 DistGen     0.00     0.00      0.0
SWITCHED SHUNT 1                   0.00     9.23      9.2
TO         3 3             1     24.82     1.01     24.8  25
TO         5 5             1    -44.82    -6.78     45.3  45
```

Bus mismatches:

	Number	Name	Area Name	Type	Mismatch MW	Mismatch Mvar	Mismatch MVA
1	5	5	1	PQ	-0.10	0.02	0.10
2	4	4	1	PQ	-0.07	0.01	0.07
3	3	3	1	PQ	-0.04	0.01	0.04
4	1	1	1	PV	-0.03	0.00	0.03
5	6	6	1	PQ	-0.00	0.00	0.00
6	7	7	1	PQ	-0.00	0.00	0.00
7	2	2	1	Slack	0.00	0.00	0.00

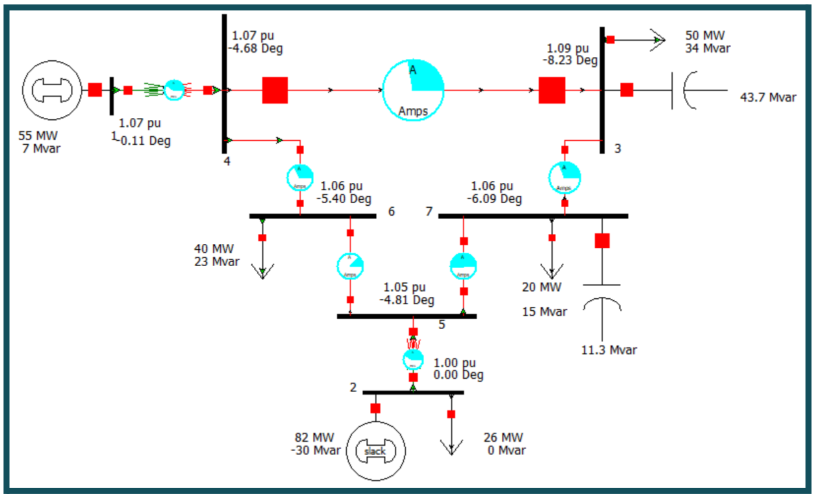
The convergence of the power flow problem is evident from the bus mismatch table as the differences between the power entering the buses and the power leaving the buses are below the convergence tolerance.

Final bus values:

	Number	Name	Area Name	Nom kV	PU Volt	Volt (kV)	Angle (Deg)	Load MW	Load Mvar	Gen MW	Gen Mvar	Switched Shunts Mvar	Act G Shunt MW	Act B Shunt Mvar	Area Num	Zone Num
1	1	1	1	34.50	1.00000	34.500	0.22			55.00	22.72		0.00	0.00	1	1
2	2	2	1	34.50	1.00000	34.500	0.00	26.00	0.00	81.57	22.35		0.00	0.00	1	1
3	3	3	1	345.00	0.95348	328.951	-8.83	50.00	34.00			33.64	0.00	0.00	1	1
4	4	4	1	345.00	0.96802	333.967	-4.94						0.00	0.00	1	1
5	5	5	1	345.00	0.96867	334.191	-5.20						0.00	0.00	1	1
6	6	6	1	345.00	0.95782	330.448	-5.76	40.00	23.00				0.00	0.00	1	1
7	7	7	1	345.00	0.96091	331.515	-6.53	20.00	15.00			9.23	0.00	0.00	1	1

(2) Power Flow Analysis Using the Newton-Raphson Method

Using only one iteration:

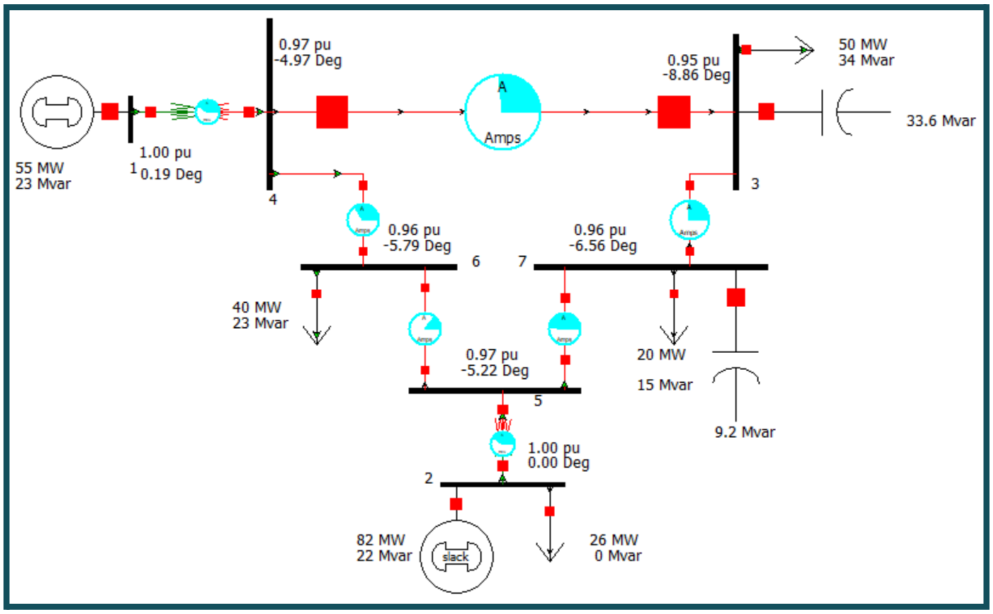



```
Bus Flows
BUS         1 1              34.5    MW      Mvar      MVA    % 1.0748  -0.11   1 1
GENERATOR 1                    55.00    7.42R   55.5
TO         4 4           1    57.87    7.42    58.3  39  1.0000TA    0.0
**** Mismatch *****            -2.87  -15.51
BUS         2 2              34.5    MW      Mvar      MVA    % 1.0000   0.00   1 1
GENERATOR 1                    81.76  -30.20R   87.2
LOAD 1                         26.00    0.00    26.0 DistGen    0.00    0.00      0.0
TO         5 5           1    55.76  -30.20    63.4  42  1.0000TA    0.0

BUS         3 3             345.0    MW      Mvar      MVA    % 1.0871  -8.23   1 1
LOAD 1                         50.00   34.00    60.5 DistGen    0.00    0.00      0.0
SWITCHED SHUNT 1                0.00   43.73    43.7
TO         4 4           1   -26.48   14.15    30.0  30
TO         7 7           1   -24.77   23.71    34.3  34
**** Mismatch *****             1.25  -28.14
BUS         4 4             345.0    MW      Mvar      MVA    % 1.0673  -4.68   1 1
TO         1 1           1   -57.87   -2.76    57.9  39  1.0000NT    0.0
TO         3 3           1    26.80  -12.26    29.5  29
TO         6 6           1    31.07   15.02    34.5  35

BUS         5 5             345.0    MW      Mvar      MVA    % 1.0514  -4.81   1 1
TO         2 2           1   -55.76   36.55    66.7  44  1.0000NT    0.0
TO         6 6           1    10.12   -8.51    13.2  13
TO         7 7           1    45.64  -28.04    53.6  54

BUS         6 6             345.0    MW      Mvar      MVA    % 1.0579  -5.40   1 1
LOAD 1                         40.00   23.00    46.1 DistGen    0.00    0.00      0.0
TO         4 4           1   -30.98  -14.50    34.2  34
TO         5 5           1   -10.10    8.67    13.3  13
**** Mismatch *****             1.08  -17.17
BUS         7 7             345.0    MW      Mvar      MVA    % 1.0612  -6.09   1 1
LOAD 1                         20.00   15.00    25.0 DistGen    0.00    0.00      0.0
SWITCHED SHUNT 1                0.00   11.26    11.3
TO         3 3           1    25.03  -22.23    33.5  33
TO         5 5           1   -45.42   29.33    54.1  54
**** Mismatch *****             0.39  -10.84
```

Bus mismatches:

	Number	Name	Area Name	Type	Mismatch MW	Mismatch Mvar	Mismatch M\
1	3	3	1	PQ	1.25	-28.14	28.16
2	6	6	1	PQ	1.08	-17.17	17.20
3	1	1	1	PV	-2.87	-15.51	15.78
4	7	7	1	PQ	0.39	-10.84	10.84
5	4	4	1	PQ	0.00	-0.00	0.00
6	5	5	1	PQ	0.00	-0.00	0.00
7	2	2	1	Slack	0.00	0.00	0.00

Using multiple iterations: (3 iterations before convergence)



The power flow list:

```
Bus Flows
BUS          1 1           34.5    MW     Mvar      MVA   % 1.0000    0.19    1 1
GENERATOR 1                   55.00   22.71R   59.5
TO          4 4          1    55.00   22.71    59.5   40   1.0000TA    0.0

BUS          2 2           34.5    MW     Mvar      MVA   % 1.0000    0.00    1 1
GENERATOR 1                   81.80   22.36R   84.8
LOAD  1                       26.00    0.00    26.0 DistGen     0.00     0.00      0.0
TO          5 5          1    55.80   22.36    60.1   40   1.0000TA    0.0

BUS          3 3          345.0    MW     Mvar      MVA   % 0.9535   -8.86    1 1
LOAD  1                       50.00   34.00    60.5 DistGen     0.00     0.00      0.0
SWITCHED SHUNT 1               0.00   33.64    33.6
TO          4 4          1   -25.31   -0.36    25.3   25
TO          7 7          1   -24.70    0.00    24.7   25

BUS          4 4          345.0    MW     Mvar      MVA   % 0.9680   -4.97    1 1
TO          1 1          1   -55.00  -17.11    57.6   38   1.0000NT    0.0
TO          3 3          1    25.61    2.11    25.7   26
TO          6 6          1    29.39   15.00    33.0   33

BUS          5 5          345.0    MW     Mvar      MVA   % 0.9687   -5.22    1 1
TO          2 2          1   -55.80  -16.65    58.2   39   1.0000NT    0.0
TO          6 6          1    10.74    8.78    13.9   14
TO          7 7          1    45.06    7.87    45.7   46

BUS          6 6          345.0    MW     Mvar      MVA   % 0.9578   -5.79    1 1
LOAD  1                       40.00   23.00    46.1 DistGen     0.00     0.00      0.0
TO          4 4          1   -29.30  -14.43    32.7   33
TO          5 5          1   -10.71   -8.57    13.7   14

BUS          7 7          345.0    MW     Mvar      MVA   % 0.9609   -6.56    1 1
LOAD  1                       20.00   15.00    25.0 DistGen     0.00     0.00      0.0
SWITCHED SHUNT 1               0.00    9.23     9.2
TO          3 3          1    24.87    1.00    24.9   25
TO          5 5          1   -44.87   -6.77    45.4   45
```

Bus mismatches:

	Number	Name	Area Name	Type	Mismatch MW	Mismatch Mvar	Mismatch MV
1	3	3	1	PQ	0.00	-0.00	0.00
2	1	1	1	PV	-0.00	-0.00	0.00
3	6	6	1	PQ	0.00	0.00	0.00
4	7	7	1	PQ	0.00	0.00	0.00
5	5	5	1	PQ	0.00	0.00	0.00
6	4	4	1	PQ	0.00	0.00	0.00
7	2	2	1	Slack	0.00	0.00	0.00

The power flow Jacobian matrix:

	Number	Name	Jacobian Equation	Angle Bus 1	Angle Bus 3	Angle Bus 4	Angle Bus 5	Angle Bus 6	Angle Bus 7	Volt Mag Bus 1	Volt Mag Bus 3	Volt Mag Bus 4	Volt Mag Bus 5	Volt Mag Bus 6	Volt Mag Bus 7
1	1	1	Voltage Magnitude							1.00					
2	1	1	Real Power	6.10		-6.10				0.55		0.57			
3	3	3	Reactive Power		-2.13	0.87			1.27		9.23	-3.68			-6.17
4	3	3	Real Power		9.48	-3.56			-5.93		1.19	-0.89			-1.32
5	4	4	Real Power	-6.10	-3.64	27.92		-18.17		-0.55	-0.39	3.91		-2.99	
6	4	4	Reactive Power	0.55	0.38	-3.79		2.86		-6.10	-3.82	28.84		-18.97	
7	5	5	Reactive Power				-4.74	1.47	2.71				34.54	-9.49	-19.01
8	5	5	Real Power				33.46	-9.09	-18.27				4.90	-1.54	-2.82
9	6	6	Reactive Power			3.38	1.65	-5.04				-18.68	-9.35	27.85	
10	6	6	Real Power			-18.08	-9.05	27.14				-3.50	-1.71	4.42	
11	7	7	Reactive Power		0.79		3.56		-4.35		-6.30		-18.71		24.80
12	7	7	Real Power		-6.01		-18.12		24.13		-0.83		-3.68		4.11

The Newton-Raphson method only took 3 iterations to converge and from the bus mismatches table, the convergence is more exact than the one from the Gauss-Seidel method. Therefore, this method shall be used in further parts of the project.

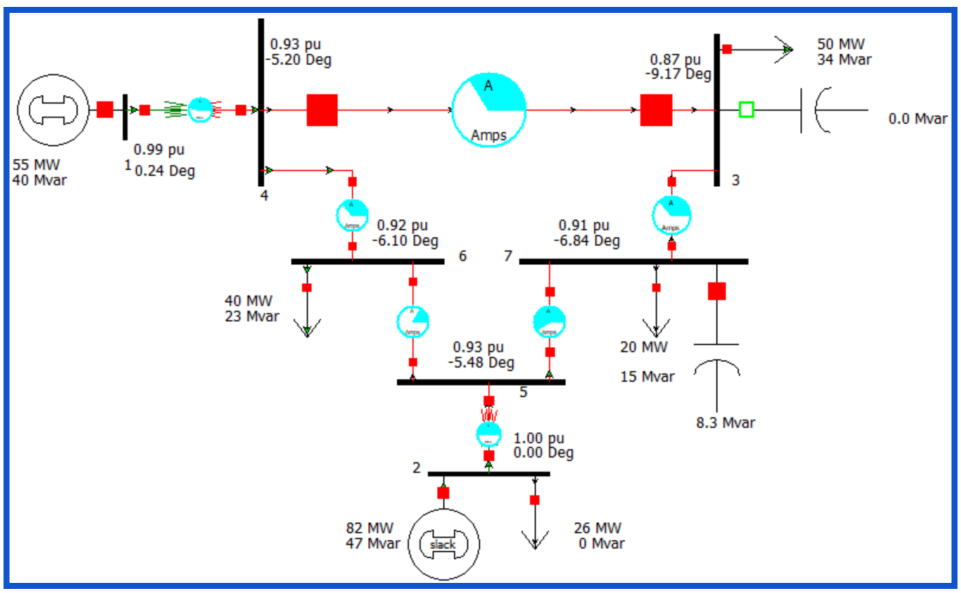
(3) Voltage Limits and Capacitor Bank at Bus 3:

The limit monitoring dialog from the previous part:

	Number	Name	Area Name	Monitor	Limit Group	PU Volt	Volt (kV)	Limit Low PU Volt	Limit High PU Volt	Contingency Limit Low PU Volt	Contingency Limit High PU Volt
1	1	1	1	YES	Default	1.00000	34.500	0.95	1.05	0.90	1.10
2	2	2	1	YES	Default	1.00000	34.500	0.95	1.05	0.90	1.10
3	3	3	1	YES	Default	0.95351	328.960	0.95	1.05	0.90	1.10
4	4	4	1	YES	Default	0.96804	333.972	0.95	1.05	0.90	1.10
5	5	5	1	YES	Default	0.96869	334.198	0.95	1.05	0.90	1.10
6	6	6	1	YES	Default	0.95784	330.453	0.95	1.05	0.90	1.10
7	7	7	1	YES	Default	0.96093	331.522	0.95	1.05	0.90	1.10

As the diagram from the previous part shows, none of the bus voltages exceed the (0.95, 1.05) pu limits. The values achieved from the Gauss-Seidel method did not violate these limits either.

However, after the capacitor bank at bus 3 was disconnected, 5 buses violated the lower voltage limit as evidenced by the limit monitoring dialog:



The limit monitoring dialog:

	Number	Name	Area Name	Monitor	Limit Group	PU Volt ▲	Volt (kV)	Limit Low PU Volt	Limit High PU Volt	Contingency Limit Low PU Volt	Contingency Limit High PU Volt
1	3	3	1	YES	Default	0.87045	300.305	0.95	1.05	0.90	1.10
2	7	7	1	YES	Default	0.91067	314.181	0.95	1.05	0.90	1.10
3	6	6	1	YES	Default	0.91815	316.763	0.95	1.05	0.90	1.10
4	4	4	1	YES	Default	0.92848	320.326	0.95	1.05	0.90	1.10
5	5	5	1	YES	Default	0.93011	320.890	0.95	1.05	0.90	1.10
6	1	1	1	YES	Default	0.98826	34.095	0.95	1.05	0.90	1.10
7	2	2	1	YES	Default	1.00000	34.500	0.95	1.05	0.90	1.10

System losses before disconnecting the shunt capacitor bank:

	From Number	From Name	To Number	To Name	Circuit	Status	Branch Device Type	Xfrmr	MW From	Mvar From	MVA From	Lim MVA	% of MVA Limit (Max)	MW Loss	Mvar Loss
1	1	1	4	4	1	Closed	Transformer	YES	55.0	22.7	59.5	150.0	39.7	0.00	5.59
2	2	2	5	5	1	Closed	Transformer	YES	55.8	22.4	60.1	150.0	40.1	0.00	5.71
3	4	4	3	3	1	Closed	Line	NO	25.6	2.1	25.7	100.0	25.7	0.30	1.75
4	3	3	7	7	1	Closed	Line	NO	-24.7	0.0	24.7	100.0	24.9	0.17	1.00
5	4	4	6	6	1	Closed	Line	NO	29.4	15.0	33.0	100.0	33.0	0.10	0.58
6	6	6	5	5	1	Closed	Line	NO	-10.7	-8.6	13.7	100.0	13.9	0.04	0.20
7	7	7	5	5	1	Closed	Line	NO	-44.9	-6.8	45.4	100.0	45.7	0.19	1.11

$$S_{loss,\,total} = 0.8\,MW \; + j15.94\,MVar$$

System losses after disconnecting the shunt capacitor bank:

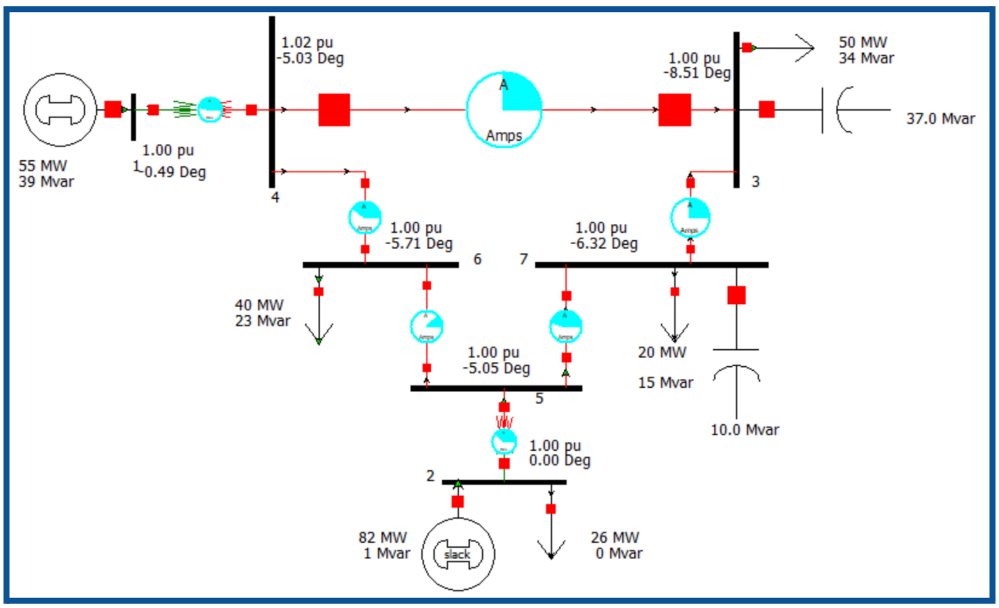
	From Number	From Name	To Number	To Name	Circuit	Status	Branch Device Type	Xfrmr	MW From	Mvar From	MVA From	Lim MVA	% of MVA Limit (Max)	MW Loss	Mvar Loss
1	1	1	4	4	1	Closed	Transformer	YES	55.0	40.0	68.0	150.0	45.3	0.00	7.48
2	2	2	5	5	1	Closed	Transformer	YES	56.3	46.9	73.3	150.0	48.8	0.00	8.48
3	4	4	3	3	1	Closed	Line	NO	25.6	18.1	31.4	100.0	31.4	0.49	2.83
4	3	3	7	7	1	Closed	Line	NO	-24.8	-18.8	31.1	100.0	32.6	0.33	1.91
5	4	4	6	6	1	Closed	Line	NO	29.3	14.5	32.7	100.0	32.7	0.11	0.62
6	6	6	5	5	1	Closed	Line	NO	-10.8	-9.2	14.1	100.0	14.3	0.04	0.24
7	7	7	5	5	1	Closed	Line	NO	-45.2	-27.4	52.8	100.0	53.9	0.29	1.67

$$S'_{loss} = 1.26\,MW \; + j23.23\,MVar$$

The system losses were notably increased due to disconnecting the shunt capacitor bank because shunt capacitor banks provide reactive power and increase transmission voltages which leads to a decrease in transmission power losses.

(4) Bus 3 Voltage Magnitude to 1.00 pu

To set the voltage magnitude of bus 3 to 1 pu, the off-nominal tap ratio of the transformer between buses 1 and 4 had to be set at 93%. Transformer tap changing is usually placed at the low voltage side of the transformer which is bus 1 in this system. By lowering the tap on the low voltage side, the turns ratio increases and allows compensation for the voltage magnitude of bus 3 which used to be 0.95 pu, and increased to 1.00 pu.

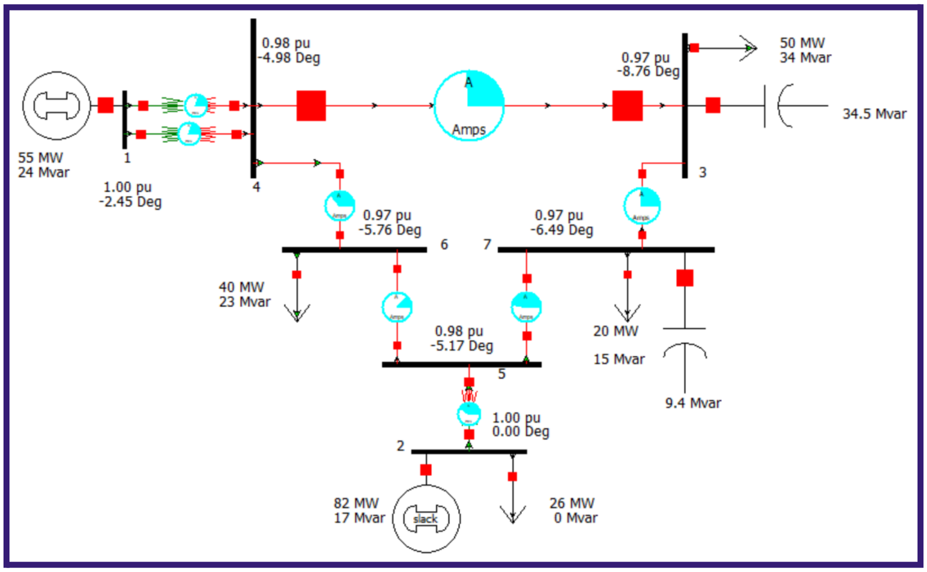


As evident by the diagram, the voltage magnitude of the rest of the buses except for buses 1 and 2 increased as well which was to be expected. None of the bus voltages violate the constraints set in the previous parts either.

	Number	Name	Area Name	Monitor	Limit Group	PU Volt	Volt (kV)	Limit Low PU Volt	Limit High PU Volt	Contingency Limit Low PU Volt	Contingency Limit High PU Volt
1	1	1	1	YES	Default	1.00001	34.500	0.95	1.05	0.90	1.10
2	2	2	1	YES	Default	1.00000	34.500	0.95	1.05	0.90	1.10
3	3	3	1	YES	Default	1.00003	345.012	0.95	1.05	0.90	1.10
4	4	4	1	YES	Default	1.02061	352.112	0.95	1.05	0.90	1.10
5	5	5	1	YES	Default	1.00183	345.631	0.95	1.05	0.90	1.10
6	6	6	1	YES	Default	1.00442	346.525	0.95	1.05	0.90	1.10
7	7	7	1	YES	Default	0.99784	344.255	0.95	1.05	0.90	1.10

(5) New Transformer Between Buses 1 and 4

By adding the new transformer with the same characteristics as the previous one, the voltage magnitudes increased while the phase of the bus voltages decreased, marking an overall improvement to the system. The real power that used to pass through only one transformer is now equally divided between the two due to their similar characteristics. The generated imaginary power, however, has increased and is equally divided between the two transformers.



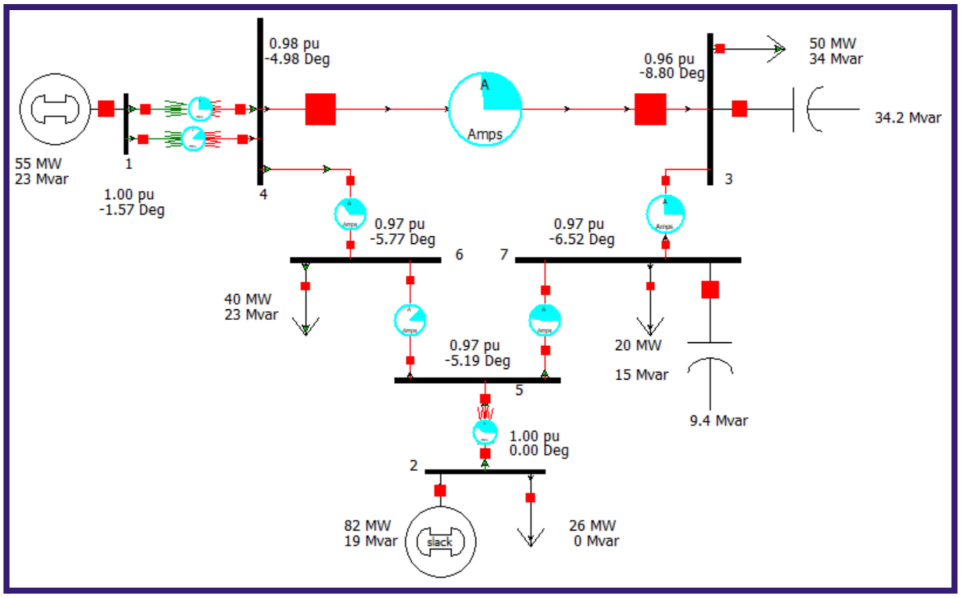
One transformer power flow:

BUS	1 1	34.5	MW	Mvar	MVA	%	1.0000	0.19	1 1
GENERATOR 1			55.00	22.71R	59.5				
TO	4 4	1	55.00	22.71	59.5	40	1.0000TA	0.0	

Two transformer power flows:

BUS	1 1	34.5	MW	Mvar	MVA	%	1.0000	-2.45	1 1
GENERATOR 1			55.00	24.03R	60.0				
TO	4 4	1	27.50	12.02	30.0	20	1.0000TA	0.0	
TO	4 4	2	27.50	12.02	30.0	20	1.0000TA	0.0	

After doubling the reactance of the new transformer, the voltage magnitudes and phases were not as improved as in the previous part, and the passing power was not equally divided between the two transformers, $\frac{2}{3}$ passed through the first transformer and $\frac{1}{3}$ the second due to its increased reactance. One noteworthy difference between the two cases of this part was that the reactive power generated in the second case was less than that of the first case.

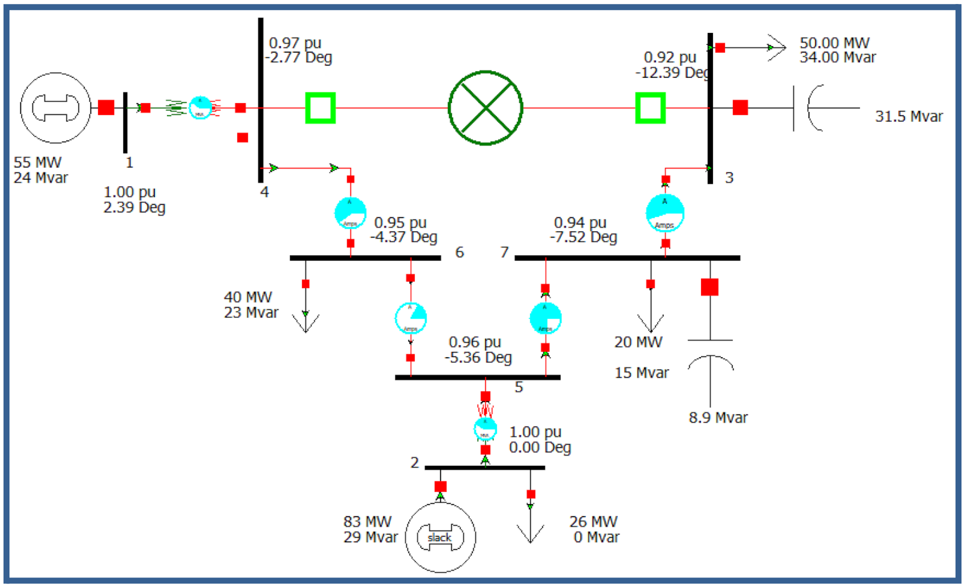


Two transformer power flows with doubled reactance:

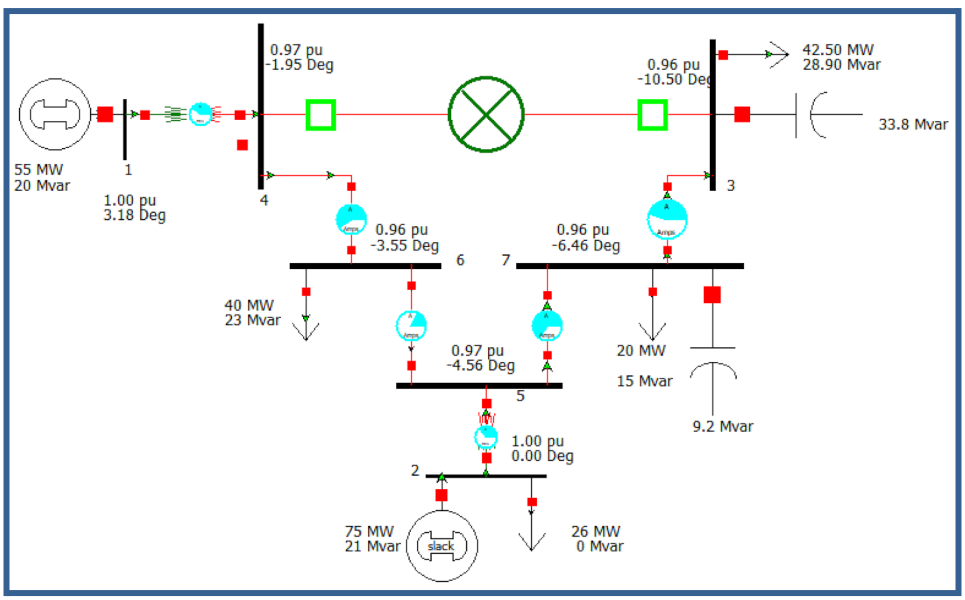
BUS 1 1	34.5		MW	Mvar	MVA	%	1.0000	-1.57	1 1
GENERATOR 1			55.00	23.49R	59.8				
TO 4 4		1	36.68	15.66	39.9	27	1.0000TA	0.0	
TO 4 4		2	18.34	7.83	19.9	13	1.0000TA	0.0	

(6) Transmission line between 3 and 4 out of service

By taking out the transmission line between bus 3 and 4, the voltage of bus 3 drops to 0.92 p.u.:



The original load at bus 3 was 50+j34 MVA we can see that by decreasing the load by 15% voltage of bus 3 increases to 0.96 p.u.:



We can also see a more precise evaluation of 0.955 p.u.:

	Number	Name	Area Name	Monitor	Limit Group	PU Volt	Volt (kV)	Limit Low PU Volt	Limit High PU Volt	Contingency Limit Low PU Volt	Contingency Limit High PU Volt
1	1	1	1	YES	Default	0.99994	34.498	0.90	1.10	0.90	1.10
2	2	2	1	YES	Default	1.00000	34.500	0.90	1.10	0.90	1.10
3	3	3	1	YES	Default	0.95513	329.519	0.90	1.10	0.90	1.10
4	4	4	1	YES	Default	0.97278	335.608	0.90	1.10	0.90	1.10
5	5	5	1	YES	Default	0.96940	334.443	0.90	1.10	0.90	1.10
6	6	6	1	YES	Default	0.96103	331.554	0.90	1.10	0.90	1.10
7	7	7	1	YES	Default	0.96126	331.635	0.90	1.10	0.90	1.10

(7) New transmission line between buses 3 and 4

Before closing the new line we had:

	From Number	From Name	To Number	To Name	Circuit	Status	Branch Device Type	Xfrmr	MW From	Mvar From	MVA From	Lim MVA	% of MVA Limit (Max)	MW Loss	Mvar Loss
1	1	1	4	4	1	Closed	Transforme	YES	55.0	22.7	59.5	150.0	39.7	0.00	5.60
2	2	2	5	5	1	Closed	Transforme	YES	55.8	22.4	60.1	150.0	40.1	0.00	5.71
3	4	4	3	3	2	Open	Line	NO	0.0	0.0	0.0	100.0	0.0	0.00	0.00
4	4	4	3	3	1	Closed	Line	NO	25.6	2.1	25.7	100.0	25.7	0.30	1.75
5	3	3	7	7	1	Closed	Line	NO	-24.7	0.0	24.7	100.0	24.9	0.17	1.00
6	4	4	6	6	1	Closed	Line	NO	29.4	15.0	33.0	100.0	33.0	0.10	0.58
7	6	6	5	5	1	Closed	Line	NO	-10.7	-8.6	13.7	100.0	13.9	0.04	0.20
8	7	7	5	5	1	Closed	Line	NO	-44.9	-6.8	45.4	100.0	45.7	0.19	1.11

After closing the new line we have:

	From Number	From Name	To Number	To Name	Circuit	Status	Branch Device Type	Xfrmr	MW From	Mvar From	MVA From	Lim MVA	% of MVA Limit (Max)	MW Loss	Mvar Loss
1	1	1	4	4	1	Closed	Transforme	YES	55.0	22.3	59.4	150.0	39.6	0.00	5.57
2	2	2	5	5	1	Closed	Transforme	YES	55.6	20.9	59.4	150.0	39.6	0.00	5.57
3	4	4	3	3	2	Closed	Line	NO	16.1	0.9	16.2	100.0	16.2	0.12	0.69
4	4	4	3	3	1	Closed	Line	NO	16.1	0.9	16.2	100.0	16.2	0.12	0.69
5	3	3	7	7	1	Closed	Line	NO	-18.0	0.5	18.0	100.0	18.1	0.09	0.52
6	4	4	6	6	1	Closed	Line	NO	22.8	15.0	27.2	100.0	27.2	0.07	0.39
7	6	6	5	5	1	Closed	Line	NO	-17.3	-8.4	19.3	100.0	19.5	0.07	0.40
8	7	7	5	5	1	Closed	Line	NO	-38.1	-5.7	38.5	100.0	38.8	0.14	0.79

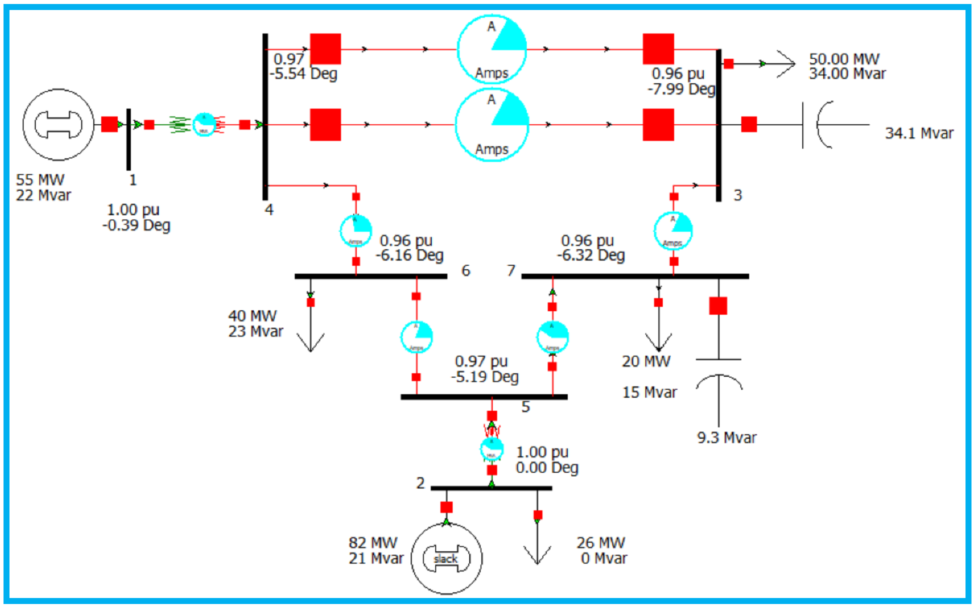
With adding the new line the total real transmitted power has increased but the imaginary power has decreased; the two lines are identical thus the total power has been divided between the two lines.

Losses before line addition: $$S_{total\ loss} = 0.8MW + j17.75Mvar$$

Losses after line addition: $$S_{totalloss} = 0.61MW + j14.62Mvar$$

Both total losses of real and imaginary power have decreased by adding a new line between buses 3 and 4.

As the impact of adding a new line on buses voltages, we can see that the magnitude has increased and the phase had decreased for buses before the line (buses 1, 4, 6) and has increased for buses after the line (buses 3, 7) and has stayed constant for middle buses (buses 2, 5).



One transmission line power flow:

BUS	3 3	345.0	MW	Mvar	MVA	%	0.9535	-8.86	1 1
LOAD 1			50.00	34.00	60.5	DistGen	0.00	0.00	0.0
SWITCHED SHUNT 1			0.00	33.64	33.6				
TO	4 4	1	-25.31	-0.34	25.3	25			
TO	4 4	2	0.00	0.00	0.0	0		(OPEN)	
TO	7 7	1	-24.70	0.02	24.7	25			
BUS	4 4	345.0	MW	Mvar	MVA	%	0.9680	-4.96	1 1
TO	1 1	1	-55.01	-17.12	57.6	38	1.0000NT	0.0	
TO	3 3	1	25.62	2.09	25.7	26			
TO	3 3	2	0.00	0.00	0.0	0		(OPEN)	
TO	6 6	1	29.40	15.03	33.0	33			

Two transmission lines power flow:

BUS	3 3	345.0	MW	Mvar	MVA	%	0.9601	-7.99	1 1
LOAD 1			50.00	34.00	60.5	DistGen	0.00	0.00	0.0
SWITCHED SHUNT 1			0.00	34.10	34.1				
TO	4 4	1	-16.01	-0.21	16.0	16			
TO	4 4	2	-16.01	-0.21	16.0	16			
TO	7 7	1	-17.99	0.54	18.0	18			
BUS	4 4	345.0	MW	Mvar	MVA	%	0.9686	-5.54	1 1
TO	1 1	1	-55.01	-16.76	57.5	38	1.0000NT	0.0	
TO	3 3	1	16.13	0.90	16.2	16			
TO	3 3	2	16.13	0.90	16.2	16			
TO	6 6	1	22.76	14.97	27.2	27			

Part II: Contingency Analysis

For parts a) and b) by using the auto insert option for opening a single transformer or line we can check contingencies for all possible outcomes of disconnecting a line or a transformer. The results are as follows:

	Label	Skip	Category	Processe	Solved	Include Remedial Actions	Screen Allow	Post-CTG AUX	Islanded Load	Islanded Gen	Global Actions	Transient Actions	Remedial Actions	Custom Monitor Violation	Violat	Max Branch %	Min Volt	Max Volt	Max Interface %	Max Bus Pair Angle	Memo
1	L_0000077345-0000055345(	NO		YES	YES	YES	NO	none			0	0	0	0	6		0.425				
2	T_000001134.5-0000044345	NO		YES	YES	YES	NO	none		55.00	0	0	0	0	5		0.853				
3	T_000002234.5-0000055345	NO		YES	YES	YES	NO	none			0	0	0	0	5		0.835				
4	L_0000044345-0000066345(	NO		YES	YES	YES	NO	none			0	0	0	0	2			1.147			
5	L_0000044345-0000033345(	NO		YES	YES	YES	NO	none			0	0	0	0	1		0.944				
6	L_0000033345-0000077345(	NO		YES	YES	YES	NO	none			0	0	0	0	1		0.931				
7	L_0000066345-0000055345(	NO		YES	YES	YES	NO	none			0	0	0	0	0						

a) Row 5 in the table refers to disconnecting the line between buses 3 and 4 as we can see that disconnection has resulted in one violation:

	Category	Element	Value	Limit	Percent	Area Name Assoc.	Nom kV Assoc.
1	Bus Low Volts	3 (3)	0.9444	0.95	99.41	1	345.0

Bus voltage drops below 0.95 p.u.

b) Row 1 refers to the disconnection between buses 5 and 7 which resulted in 6 violations:

	Category	Element	Value	Limit	Percent	Area Name Assoc.	Nom kV Assoc.
1	Bus Low Volts	1 (1)	0.7598	0.95	79.98	1	34.50
2	Bus Low Volts	3 (3)	0.4634	0.95	48.78	1	345.0
3	Bus Low Volts	4 (4)	0.7027	0.95	73.96	1	345.0
4	Bus Low Volts	5 (5)	0.841	0.95	88.52	1	345.0
5	Bus Low Volts	6 (6)	0.7349	0.95	77.36	1	345.0
6	Bus Low Volts	7 (7)	0.4249	0.95	44.72	1	345.0

Buses voltages drop below 0.95p.u.

c) For this part we use the move option for generators and 100% of the generator at bus 2 to bus 3:

	Label	Skip	Category	Processe	Solved	Include Remedial Actions	Screen Allow	Post-CTG AUX	Islanded Load	Islanded Gen	Global Actions	Transient Actions	Remedial Actions	Custom Monitor Violation	Violat	Max Branch %	Min Volt	Max Volt	Max Interface %	Max Bus Pair Angle	Memo
1	move gen from bus 2 to 3	NO		YES	YES	YES	NO	none			0	0	0	0	2			1.087			

This action has resulted in 2 violations:

	Category	Element	Value	Limit	Percent	Area Name Assoc.	Nom kV Assoc.
1	Bus High Volts	1 (1)	1.087	1.050	103.52	1	34.50
2	Bus High Volts	3 (3)	1.050	1.050	100.04	1	345.0

Buses voltages go over 1.05 p.u.

Discussion

1. What are the advantages of the Gauss-Seidel method and the Newton-Raphson method respectively?

The Gauss-seidel method is an iterative method that has less computation for each iteration due to the linear and less complicated nature of the method which then requires a larger number of iterations to achieve convergence and as seen in the first part of this project, the convergence is less exact than the one achieved from the Newton-Raphson method. Due to the lessened computation, Gauss-Seidel requires less memory but because of the large number of iterations needed until convergence, this method is more fit for smaller systems with fewer buses that require fewer iterations and because of the lesser time it takes for each iteration, it might even yield quicker results for smaller systems than the Newton-Raphson method.

The Newton-Raphson method in contrast uses more exact criteria and quadratic equations to achieve a more reliable and exact convergence in fewer iterations but it takes more time during each iteration. The total time until convergence, however, is less than that of the Gauss-Seidel method and because the number of iterations until convergence is independent of the size of the system, it is more appropriate for larger systems with more buses.

Gauss-Seidel method	**Newton-Raphson method**
Needs less Computational time per iteration.	Needs more Computational time per iteration.
Less memory is needed.	More memory is needed.
More iterations until convergence.	Fewer iterations until convergence.
The total time until convergence is more.	The total time until convergence is less.
The number of iterations depends on the size of the system.	The number of iterations is independent of the size of the system.
Convergence criteria depend on the selection of	Convergence criteria are independent of the

slack bus.	selection of slack bus.
Unreliable and inexact convergence.	Reliable and exact convergence.
Used for smaller systems.	Used for larger systems.

Table 1 - a summary of the comparison:

2. Comment on the effects of the presence of enough shunt capacitors in power system operation.

The primary function of shunt capacitors is to provide reactive power to compensate for lagging VARs caused by inductive loads, improving the power factor of the system and reducing the overall demand for reactive power from the power source. By improving the power factor, shunt capacitors can reduce the amount of reactive power drawn from the grid, leading to lower energy losses and more efficient operation of electrical equipment, which then leads to increased load capacity. Shunt capacitors can also help maintain stable voltage levels by reducing voltage drops caused by reactive power consumption, particularly in situations of high inductive load.

In part 3 of this project, a shunt capacitor was disconnected, and the voltage magnitude of all buses decreased while transmission losses increased which follows the previous reasoning and highlights the advantages of shunt capacitor banks.

The main disadvantage of shunt capacitor banks is that their reactive power output is proportional to the square of the voltage and consequently when the voltage is low and the system needs them most, they are the least efficient. Another disadvantage is that shunt capacitors can worsen voltage stability in some cases, especially when their installation leads to overvoltage conditions during light load periods. Shunt capacitor banks also require careful monitoring and control to make sure they do not cause issues such as reactive power overcompensation or undercompensation.

3. Comment on the data required for optimum power flow analysis in this software.

PowerWorld's power flow analysis uses a power flow algorithm that includes common controls. These controls include:

Remote voltage regulation

Shared voltage regulation

Phase-shifting transformer control

DC line modeling

Multi-Terminal DC Line Modeling

PowerWorld's Optimal Power Flow Analysis Tool (OPF) can dispatch generation in an area or group of areas. It can also enforce transmission line and interface limits.

Power flow analysis is a traditional power engineering calculation that determines the flows on all lines and the voltages at all buses in a system. Power flow analysis can help prevent power system overloads and decrease the risk of a short circuit or a blowout.

For the power flow equations, we have:

$$I = Y_{bus}V$$

$$S = VI^*$$

In each electrical island, exactly one bus is the slack bus which provides voltage and phase reference. In this bus, the voltage magnitude and phase are fixed, and real and reactive power may vary.

We should also have PV buses, a generator bus with voltage magnitude, and real power fixed.

Another bus type is the PQ bus which has fixed real and reactive powers.

Therefore, to solve a power flow problem admittance of each line, the slack bus and its voltage phase and magnitude, voltage magnitude and real power of generator buses, and lastly powers of load buses are needed.

The line admittances can be computed with information on line length and its impedances.

4. Comment on the possible ways to improve the reliability and resilience of system operation.

The first approach to improve the reliability of the system is to base the system on reference designs that have been validated for specific applications.

A pre-engineered electrical distribution system, validated for a specific application, includes a core power system design and a digital layer for power management. The design incorporates backup power and power conditioning elements like generators, UPS, ATS, and harmonic filtering. It adheres to local and international standards, prioritizing safety to prevent harm to individuals and equipment. This reference design streamlines the design-build process, reducing risk and cost. Specialized software optimizes the system for its application, considering current and future operational and environmental conditions, thereby future-proofing the facility.

Another approach would be having a power management system. Hidden risks to reliability in power distribution systems can be mitigated with a fully digitized electrical system, which is resilient to power disturbances and downtime. A power management system uses data from connected devices to continuously monitor system performance and assets. Alarms alert personnel to unexpected conditions for immediate action. The network includes intelligent power meters that identify power quality issues and faults, with diagnostic tools for root cause analysis. The system also features wireless thermal sensors for early detection of abnormal temperature rises, reducing fire or failure risks and avoiding annual IR testing costs. Monitoring circuit breaker health and aging with advanced analytics enables proactive maintenance, prevents performance issues, extends breaker life, and ensures 24/7 availability of clean, stable power, thereby reducing operational costs.