POWER FLOW PROJECT

PowerWorld Simulation

ABSTRACT

This report is the detailed study of power system analysis in PowerWorld simulator

Power flow analysis

In figure 1 we have provided we the power system single line diagram to be observed in PowerWorld simulator in comparison with MATLAB software. All the data tables of Generators, Transformers, Busbars, Loads and Transmission lines also provided.

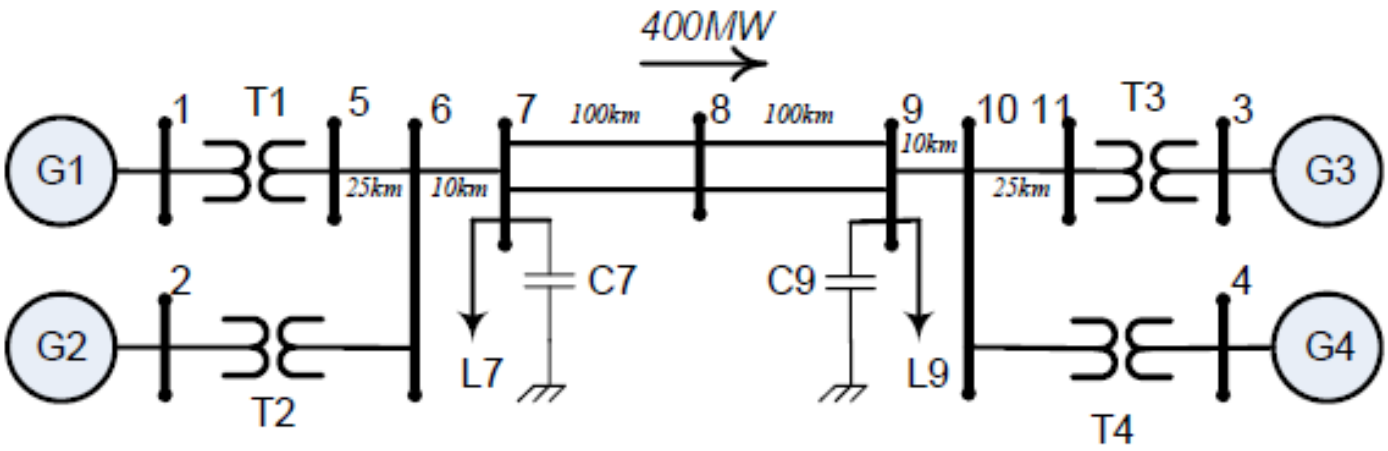


Figure 1. Single-line diagram of a two-area power system.

figure 1 SLD of the given system.

Task 1: Based on figure1 we develop simulation in PowerWorld as shown in figure2. Which we set as a base case for further studies.

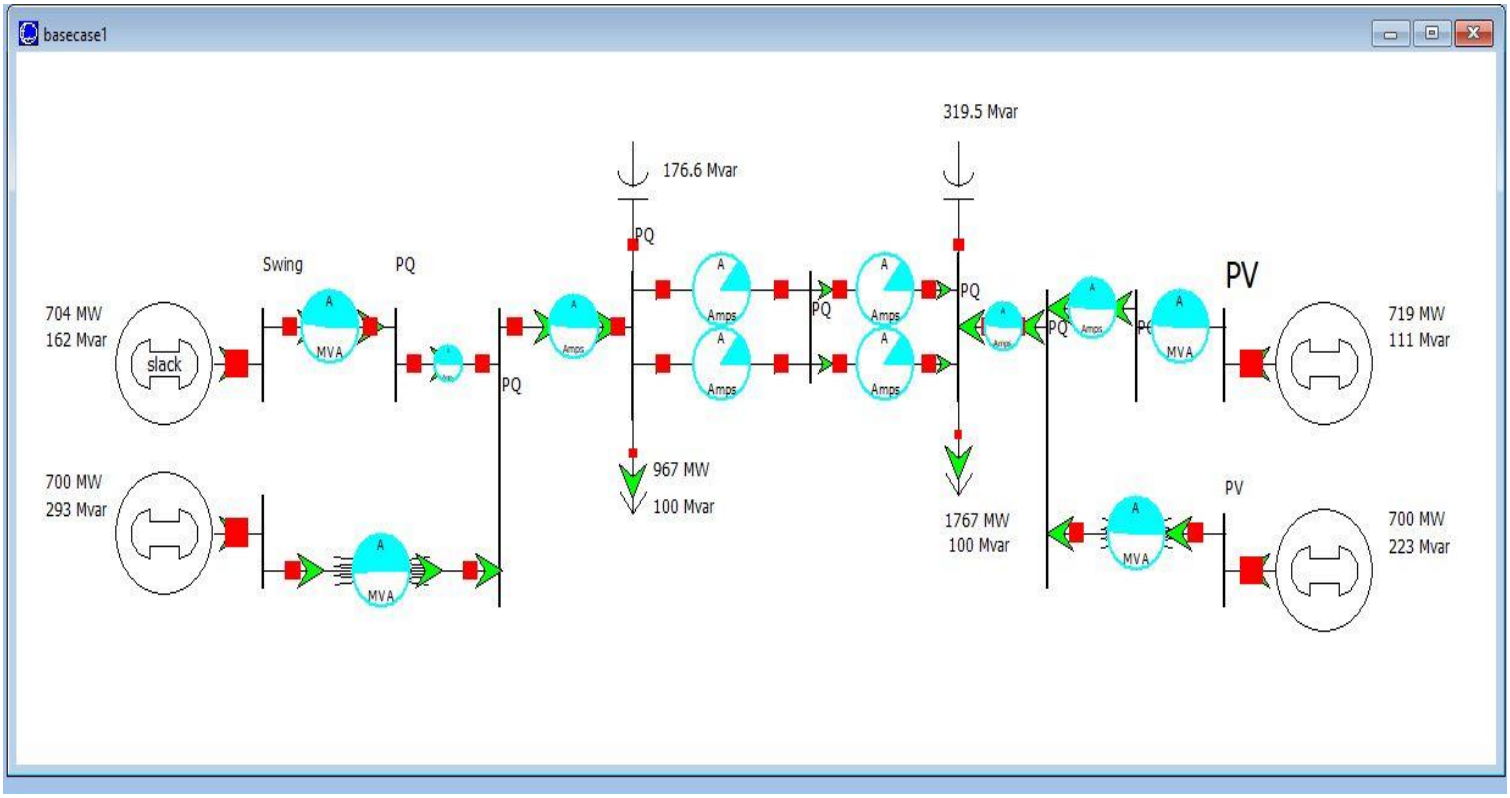


figure 2 Base case

Above figure is the simulation result of the given 11 bus system in PowerWorld simulator whom we set as a "Base case".

Below is the Model Explorer of the base case,

Bus Records

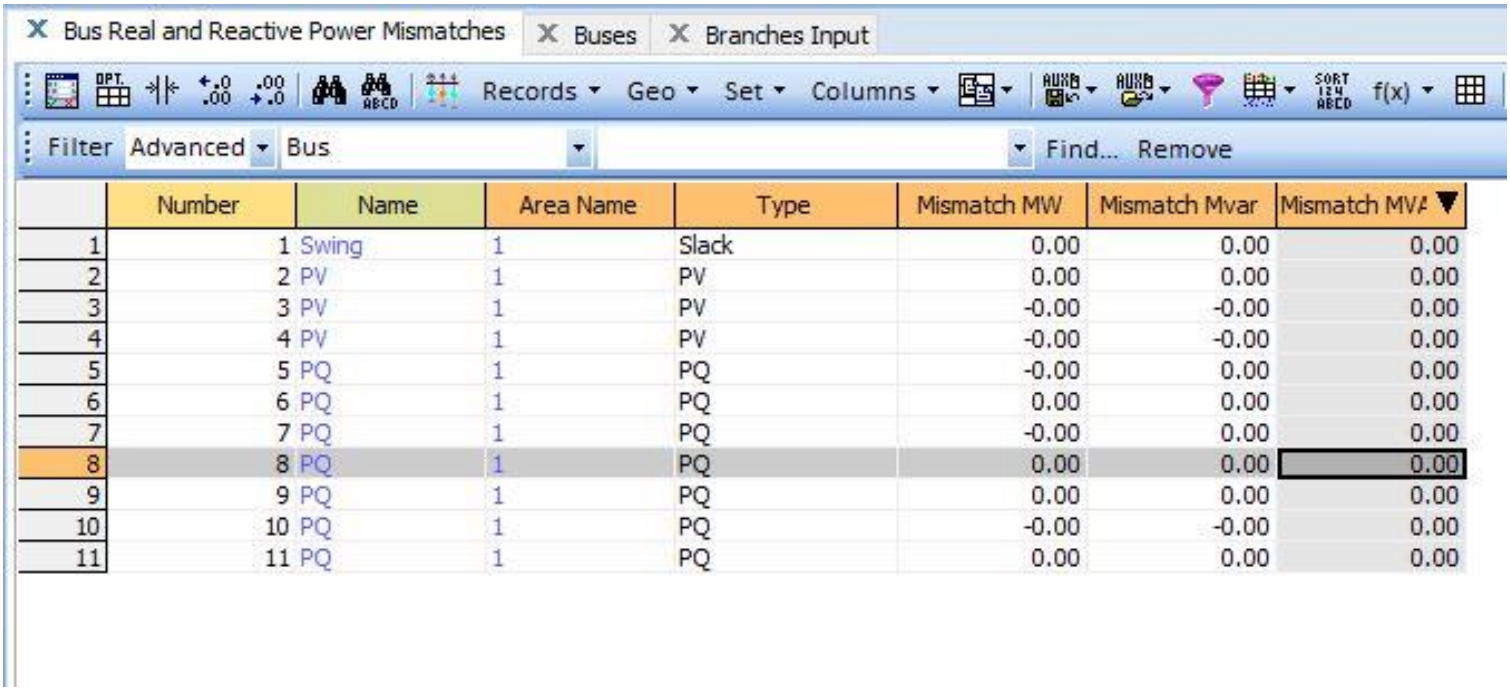
Records Geo Set Columns f(x) Options

Filter Advanced Bus Find... Remove

	Number	Name	Area Name	Nom kV	PU Volt	Volt (kV)	Angle (Deg)	Load MW	Load Mvar	Gen MW	Gen Mvar	Switched Shunts Mvar
1	1	Swing	1	20.00	1.00000	20.000	0.00			703.77	162.16	
2	2	PV	1	20.00	1.00000	20.000	-10.55			700.00	293.47	
3	3	PV	1	20.00	1.00000	20.000	-35.17			719.00	111.42	
4	4	PV	1	20.00	1.00000	20.000	-39.59			700.00	222.52	
5	5	PQ	1	230.00	0.98022	225.451	-6.76					
6	6	PQ	1	230.00	0.95877	220.517	-17.43					
7	7	PQ	1	230.00	0.93963	216.116	-26.21	967.00	100.00			176.58
8	8	PQ	1	230.00	0.92755	213.336	-40.81					
9	9	PQ	1	230.00	0.95544	219.750	-55.03	1767.00	100.00			319.50
10	10	PQ	1	230.00	0.97032	223.174	-46.38					
11	11	PQ	1	230.00	0.99824	229.596	-35.84					

figure 3 model Explorer data

1) From model explorer data the voltage at bus#8 is 213.336 kV
2) With the voltage angle at bus # 8 is -40.81 degrees.



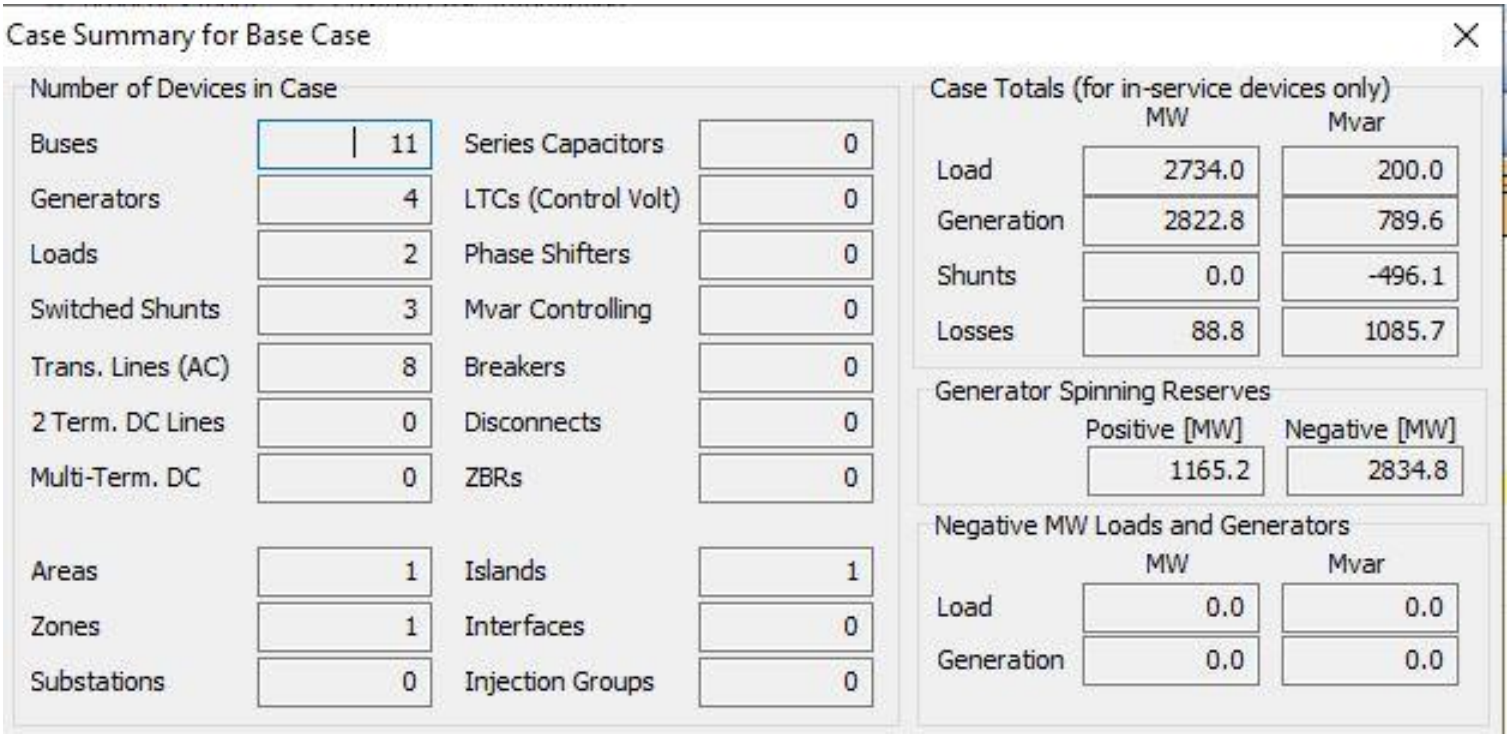
Bus Real and Reactive Power Mismatches | Buses | Branches Input

Records | Geo | Set | Columns | f(x)

Filter: Advanced | Bus | Find... | Remove

	Number	Name	Area Name	Type	Mismatch MW	Mismatch Mvar	Mismatch MVA
1	1	Swing	1	Slack	0.00	0.00	0.00
2	2	PV	1	PV	0.00	0.00	0.00
3	3	PV	1	PV	-0.00	-0.00	0.00
4	4	PV	1	PV	-0.00	-0.00	0.00
5	5	PQ	1	PQ	-0.00	0.00	0.00
6	6	PQ	1	PQ	0.00	0.00	0.00
7	7	PQ	1	PQ	-0.00	0.00	0.00
8	8	PQ	1	PQ	0.00	0.00	0.00
9	9	PQ	1	PQ	0.00	0.00	0.00
10	10	PQ	1	PQ	-0.00	-0.00	0.00
11	11	PQ	1	PQ	0.00	0.00	0.00

figure 4 MW & MVAR Mismatch at buses (No mismatch)



Case Summary for Base Case

Number of Devices in Case

Buses	11	Series Capacitors	0
Generators	4	LTCs (Control Volt)	0
Loads	2	Phase Shifters	0
Switched Shunts	3	Mvar Controlling	0
Trans. Lines (AC)	8	Breakers	0
2 Term. DC Lines	0	Disconnects	0
Multi-Term. DC	0	ZBRs	0
Areas	1	Islands	1
Zones	1	Interfaces	0
Substations	0	Injection Groups	0

Case Totals (for in-service devices only)

	MW	Mvar
Load	2734.0	200.0
Generation	2822.8	789.6
Shunts	0.0	-496.1
Losses	88.8	1085.7

Generator Spinning Reserves

Positive [MW]	Negative [MW]
1165.2	2834.8

Negative MW Loads and Generators

	MW	Mvar
Load	0.0	0.0
Generation	0.0	0.0

figure 5 Base case summary

3) From the above figure 4 base case summary, the generation is 2822.8 MW and load is 2734MW which results in 88.8MW loss of power. Similarly, MVAR losses are 1085.7Mvar.

4) From figure 2 model explorer data the actual voltage (in kV) at all buses are as below:

Bus Records

Volt (kV)

1. 20.000
2. 20.000
3. 20.000
4. 20.000
5. 225.451
6. 220.517
7. 216.116
8. 213.336
9. 219.750
10. 223.174
11. 229.596

Task2: Running the data information provided in MATLAB as shown in below figure.

bus11.m

```
clear
basemva=100;
accuracy=0.001;
maxiter=12;
%        Bus Bus  Voltage Angle   ---Load---- -------Generator-----    Injected
%        No  Type Mag.    Degree  MW    Mvar  MW    Mvar  Qmin     Qmax   Mvar
busdata=[1   1    1.03    0.0     0.0   0.0   0.0   0.0 -1000     1000       0
         2   2    1.01    0.0     0.0   0.0  700.0  0.0 -1000     1000       0
         3   2    1.03    0.0     0.0   0.0  719.0  0.0 -1000     1000       0
         4   2    1.01    0.0     0.0   0.0  700.0  0.0 -1000     1000       0
         5   3    0       0.0     0.0   0.0    0.0  0.0   0       0          0
         6   3    0       0.0     0.0   0.0    0.0  0.0   0       0          0
         7   3    0       0.0   967.0 100.0    0.0  0.0   0       0        200
         8   3    0       0.0     0.0   0.0    0.0  0.0   0       0          0
         9   3    0       0.0  1767.0 100.0    0.0  0.0   0       0        350
        10   3    0       0.0     0   0.0    0.0  0.0   0       0          0
        11   3    0       0.0     0.0   0.0    0.0  0.0   0       0          0];

    %                                        Line code
    %         Bus bus   R        X   1/2 B   = 1 for lines
    %         nl  nr  p.u.      p.u.     p.u.     > 1 or < 1 tr. tap at bus nl
    linedata=[1   5   0         0.0164   0          1
              5   6   0.0025    0.0250   0.0437     1
              2   6   0         0.0164   0          1
              6   7   0.0010    0.0100   0.0175     1
              7   8   0.0110    0.1100   0.1925     1
              7   8   0.0110    0.1100   0.1925     1
              8   9   0.0110    0.1100   0.1925     1
              8   9   0.0110    0.1100   0.1925     1
              9   10   0.0010   0.0100   0.0175     1
              4   10   0        0.0164   0          1
              10  11   0.0025   0.0250   0.0437     1
              3   11   0        0.0164   0          1];

        lfybus
        lfnewton
        busout
        lineflow
```

figure 6 MATLAB Simulation of 11 bus system in figure1.

But unfortunately, because of some indexing error I can't get the output as shown in below figure.

```
>> bus11
Index exceeds the number of array elements (4).

Error in lfnewton (line 83)
      DC(nn) = P(n)-Pk;

Error in bus11 (line 36)
      lfnewton
```

figure 7 code error.

Task 3: From figure3 there is voltage violation in base case at bus 7 (0.93p.u) & bus 8(0.92p.u) that is below the range value (0.95-1.05 p.u.).

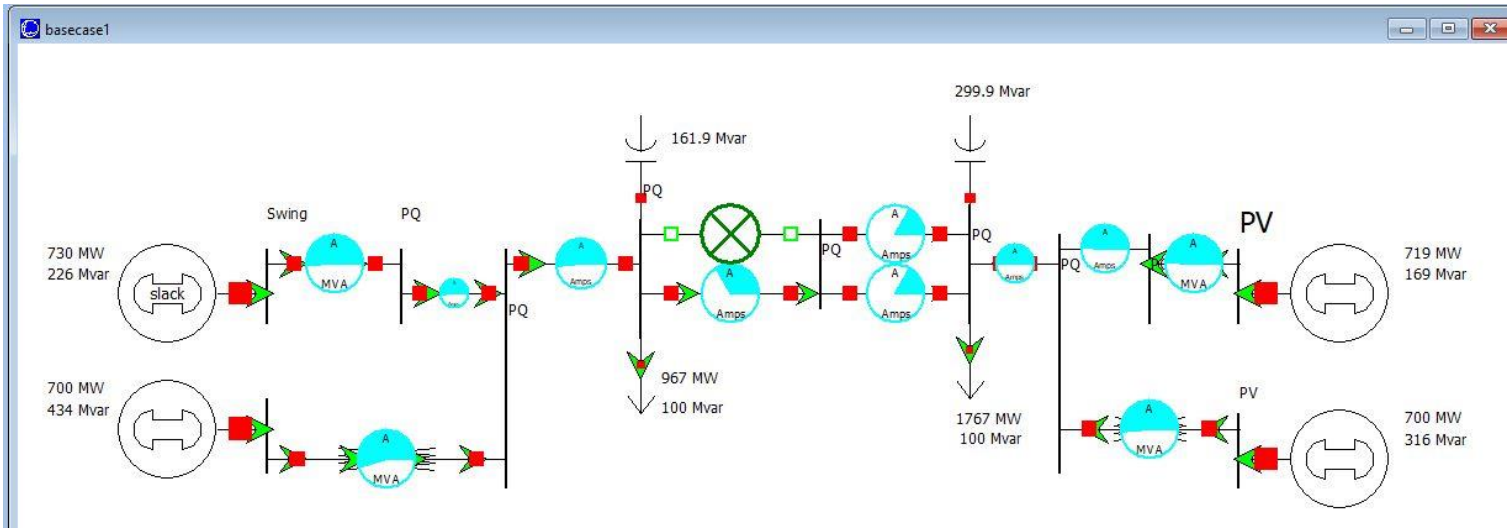


figure 8 Transmission line trip b/w bus 7 and bus8

After tripping a transmission line between bus 7 and bus 8 we find further voltage violation at 4 buses;

1) 0.93 p.u at bus 6
2) 0.89 p.u at bus 7
3) 0.84p.u bus 8
4) 0.92 p.u at bus 9

as shown in figure7.

Bus Records

Records Geo Set Columns f(x) Options

Filter Advanced Bus Find... Remove

	Number	Name	Area Name	Nom kV	PU Volt	Volt (kV)	Angle (Deg)	Load MW	Load Mvar	Gen MW	Gen Mvar	Switched Shunts Mvar
1	1	Swing	1	20.00	1.00000	20.000	0.00			729.98	225.78	
2	2	PV	1	20.00	1.00000	20.000	-11.42			700.00	433.67	
3	3	PV	1	20.00	1.00000	20.000	-61.03			719.00	168.88	
4	4	PV	1	20.00	1.00000	20.000	-65.43			700.00	316.43	
5	5	PQ	1	230.00	0.97038	223.188	-7.09					
6	6	PQ	1	230.00	0.93595	215.267	-18.47					
7	7	PQ	1	230.00	0.89982	206.958	-27.93	967.00	100.00			161.93
8	8	PQ	1	230.00	0.84054	193.324	-64.55					
9	9	PQ	1	230.00	0.92571	212.912	-81.32	1767.00	100.00			299.93
10	10	PQ	1	230.00	0.95503	219.657	-72.34					
11	11	PQ	1	230.00	0.99730	229.379	-61.71					

figure 9 Voltage violation at 4 buses after Transmission line (7-8) trip.

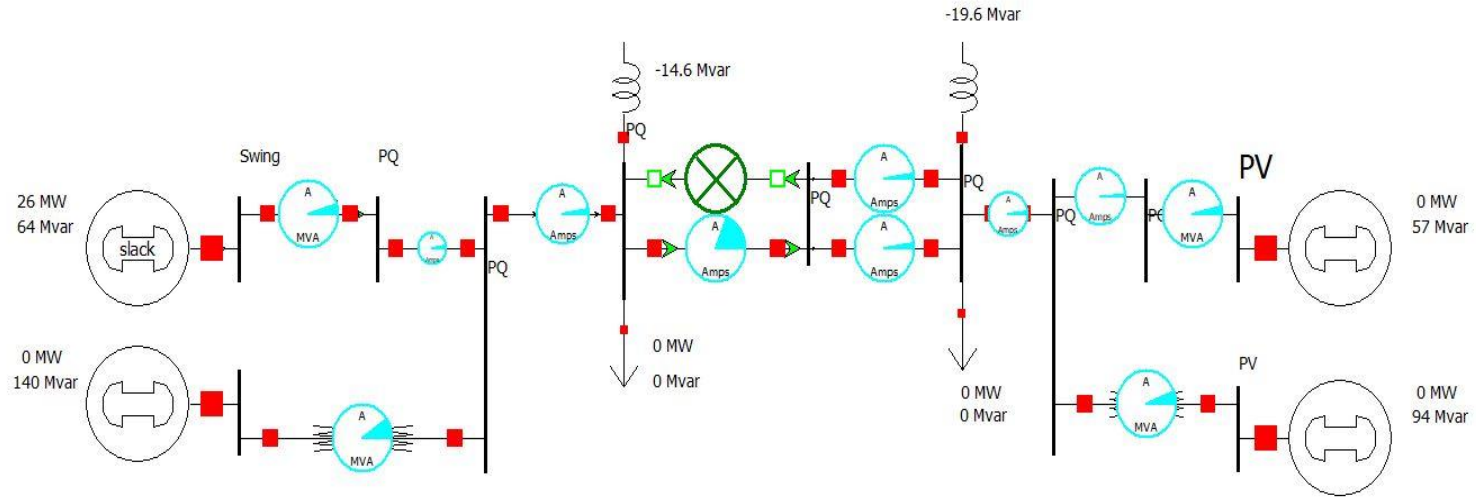


figure 10 Difference flow after Transmission line (7-8) trip.

Task 4: To reduce the voltage violation at different buses because of transmission line trip we adjust a shunt capacitor bank at bus 8 as shown in figure 8. By increasing the capacitor bank value from 50MVAR to 100MVAR and then 150MVAR the voltage violation is reduced at buses. At nominal 150MVAR the voltage at bus 8 becomes 0.95p.u as shown in figure 9. While the I^2R losses increased from base case (88MW) to 100MW by a difference of 12MW as clear from figure 10.

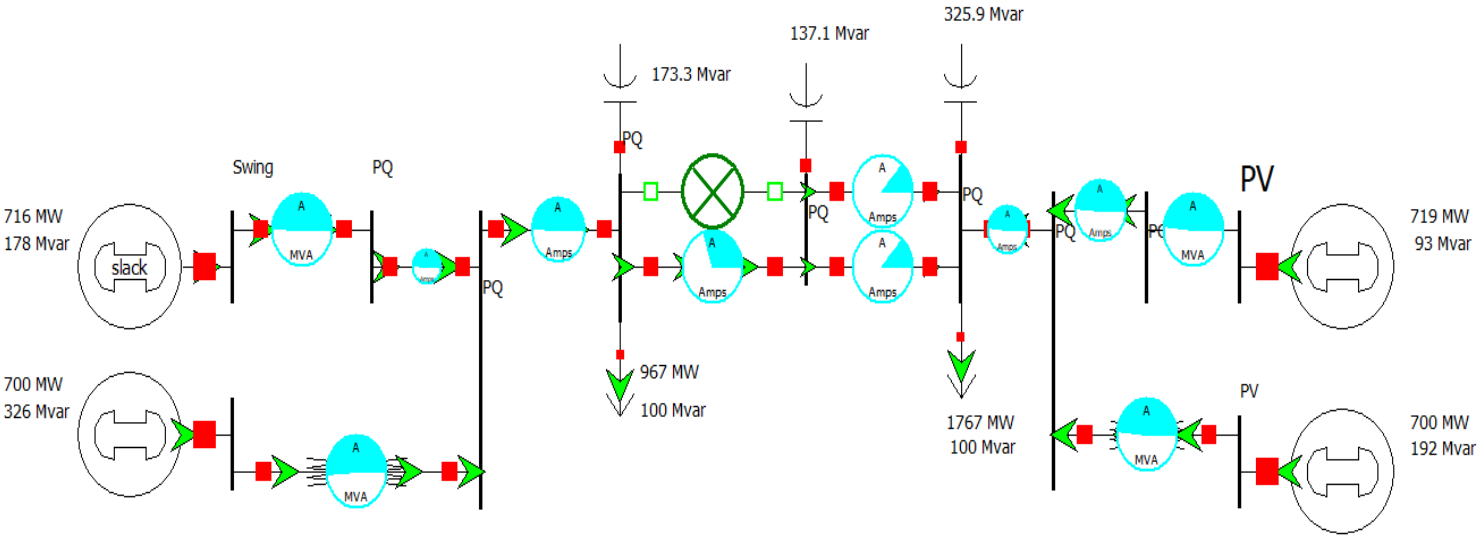
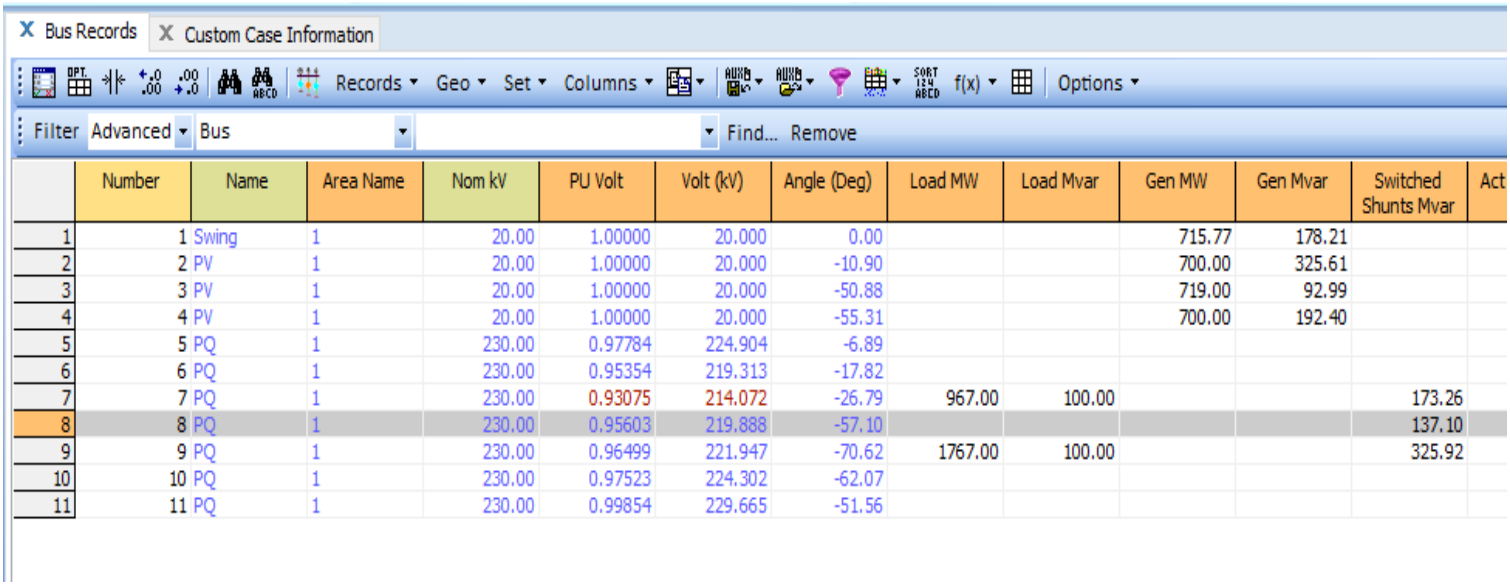


figure 11 compensating shunt capacitor bank at bus 8.



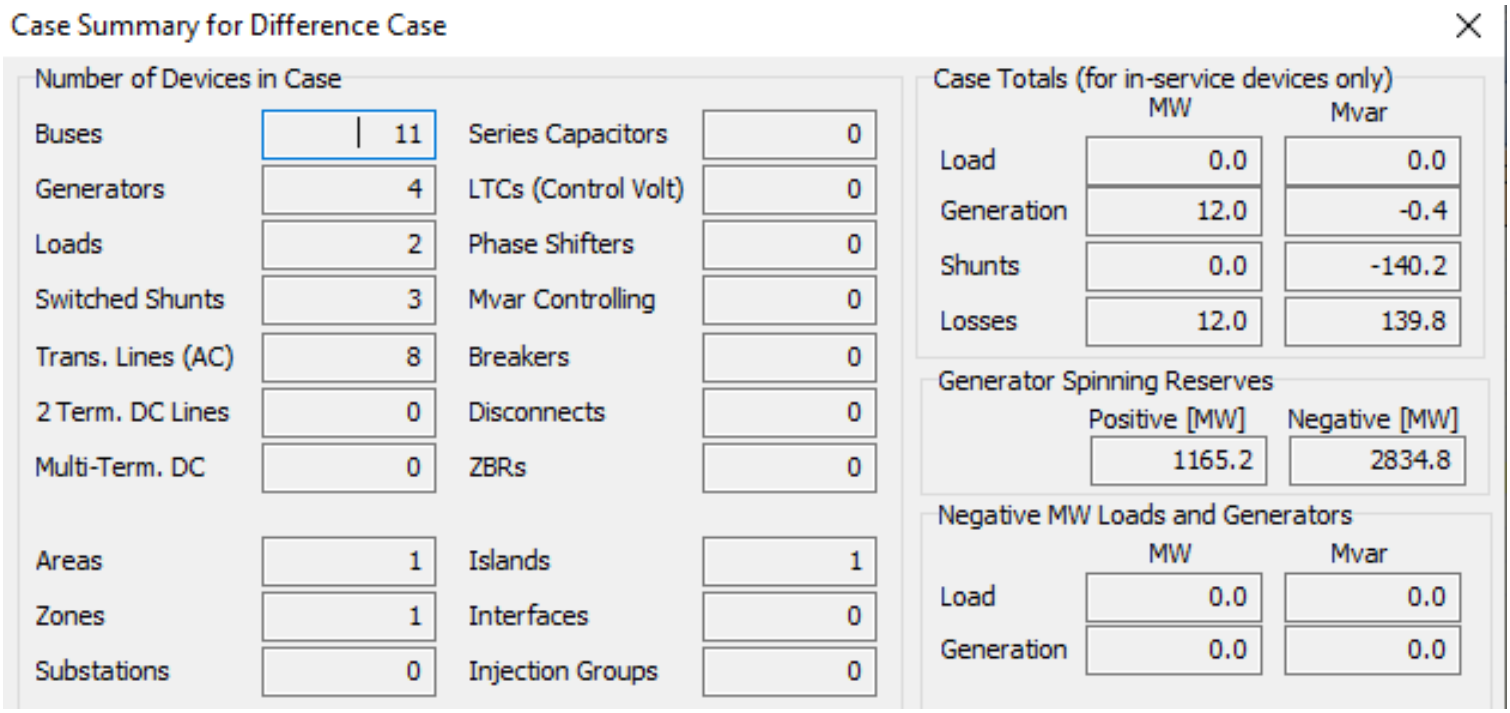
Bus Records | Custom Case Information

Records | Geo | Set | Columns | Options

Filter: Advanced | Bus | Find... | Remove

	Number	Name	Area Name	Nom kV	PU Volt	Volt (kV)	Angle (Deg)	Load MW	Load Mvar	Gen MW	Gen Mvar	Switched Shunts Mvar	Act
1	1	Swing	1	20.00	1.00000	20.000	0.00			715.77	178.21		
2	2	PV	1	20.00	1.00000	20.000	-10.90			700.00	325.61		
3	3	PV	1	20.00	1.00000	20.000	-50.88			719.00	92.99		
4	4	PV	1	20.00	1.00000	20.000	-55.31			700.00	192.40		
5	5	PQ	1	230.00	0.97784	224.904	-6.89						
6	6	PQ	1	230.00	0.95354	219.313	-17.82						
7	7	PQ	1	230.00	0.93075	214.072	-26.79	967.00	100.00			173.26	
8	8	PQ	1	230.00	0.95603	219.888	-57.10					137.10	
9	9	PQ	1	230.00	0.96499	221.947	-70.62	1767.00	100.00			325.92	
10	10	PQ	1	230.00	0.97523	224.302	-62.07						
11	11	PQ	1	230.00	0.99854	229.665	-51.56						

figure 12 AT 150MVAR V8 is 0.95P.U.



Case Summary for Difference Case

Number of Devices in Case

Buses	11	Series Capacitors	0
Generators	4	LTCs (Control Volt)	0
Loads	2	Phase Shifters	0
Switched Shunts	3	Mvar Controlling	0
Trans. Lines (AC)	8	Breakers	0
2 Term. DC Lines	0	Disconnects	0
Multi-Term. DC	0	ZBRs	0
Areas	1	Islands	1
Zones	1	Interfaces	0
Substations	0	Injection Groups	0

Case Totals (for in-service devices only)

	MW	Mvar
Load	0.0	0.0
Generation	12.0	-0.4
Shunts	0.0	-140.2
Losses	12.0	139.8

Generator Spinning Reserves

Positive [MW]	Negative [MW]
1165.2	2834.8

Negative MW Loads and Generators

	MW	Mvar
Load	0.0	0.0
Generation	0.0	0.0

figure 13 I^2R losses 12 MW.

Task 5: Isolating capacitor bank at bus 7 and changing the tap ratio of transformer, 14 MW generation decrease occurs at slack generator and 104 MVAR change at generator 2.

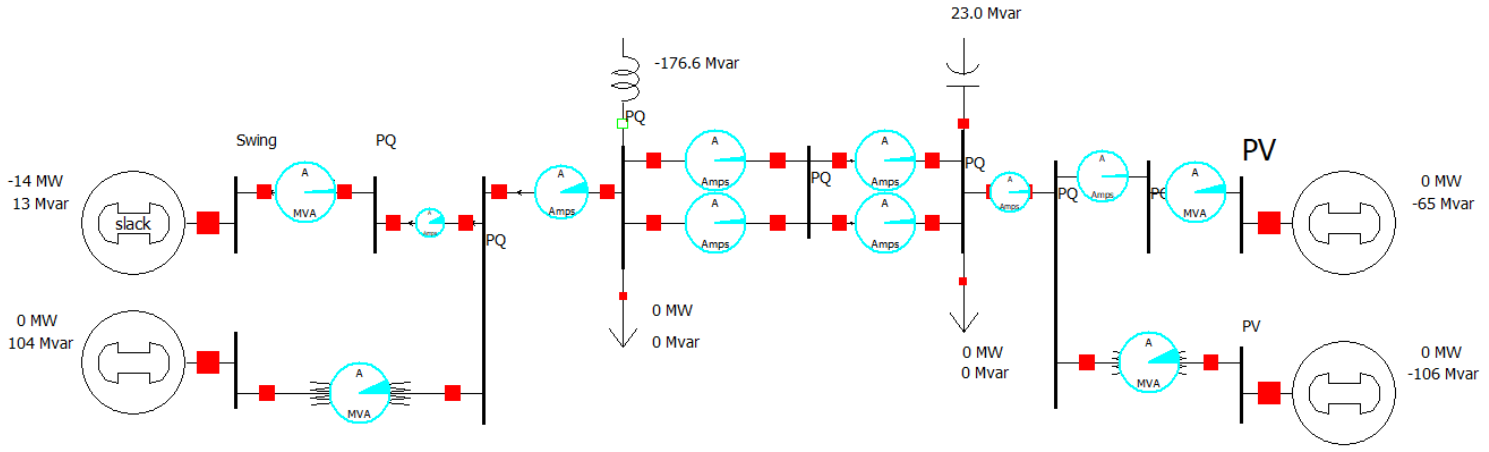


figure 14 Task 5 difference flow.

After changing taps of transformer and isolation of capacitor bank at bus 7 the voltage violation at bus 5,6,7 is shown in below figure.

Bus Records | Ybus

Records | Geo | Set | Columns | f(x) | Options

Filter: Advanced | Bus | Find... | Remove

	Name	Area Name	Nom kV	PU Volt	Volt (kV)	Angle (Deg)	Load MW	Load Mvar	Gen MW	Gen Mvar	Switched Shunts Mvar
1	Swing	1	20.00	1.00000	20.000	0.00			689.56	174.82	
2	PV	1	20.00	1.00000	20.000	-7.28			700.00	397.41	
3	PV	1	20.00	1.00000	20.000	-21.97			719.00	46.33	
4	PV	1	20.00	1.00000	20.000	-26.41			700.00	116.14	
5	PQ	1	230.00	1.15610	265.904	-4.77					
6	PQ	1	230.00	1.12531	258.821	-12.25					
7	PQ	1	230.00	1.08846	250.346	-18.56	967.00	100.00			0.00
8	PQ	1	230.00	1.02922	236.720	-29.48					
9	PQ	1	230.00	0.98918	227.512	-41.39	1767.00	100.00			342.47
10	PQ	1	230.00	0.98765	227.159	-33.08					
11	PQ	1	230.00	0.99931	229.841	-22.65					

figure 15 Voltage violation after capacitor bank removal and transformer taps at 0.85.

The 14 MW difference at slack bus increases by 1MW as we by an increment of 0.01 transformer tapping. And the buses voltages also getting stable. At tapping 0.95 all the buses get stable voltage except bus8 as shown in below data explorer model.

Filter Advanced Bus Find... Remove

	Number	Name	Area Name	Nom kV	PU Volt	Volt (kV)	Angle (Deg)	Load MW	Load Mvar	Gen MW	Gen Mvar	Switched Shunts Mvar
1	1	Swing	1	20.00	1.00000	20.000	0.00			701.23	201.78	
2	2	PV	1	20.00	1.00000	20.000	-9.52			700.00	416.77	
3	3	PV	1	20.00	1.00000	20.000	-32.22			719.00	103.65	
4	4	PV	1	20.00	1.00000	20.000	-36.64			700.00	209.81	
5	5	PQ	1	230.00	1.02702	236.215	-6.11					
6	6	PQ	1	230.00	0.99370	228.551	-15.82					
7	7	PQ	1	230.00	0.95665	220.029	-24.02	967.00	100.00			0.00
8	8	PQ	1	230.00	0.93953	216.092	-38.11					
9	9	PQ	1	230.00	0.95946	220.677	-52.03	1767.00	100.00			322.20
10	10	PQ	1	230.00	0.97239	223.650	-43.42					
11	11	PQ	1	230.00	0.99837	229.625	-32.89					

figure 16 bus voltages.

At this point the power loss is 2MW less than base case as clear from the case summary below.

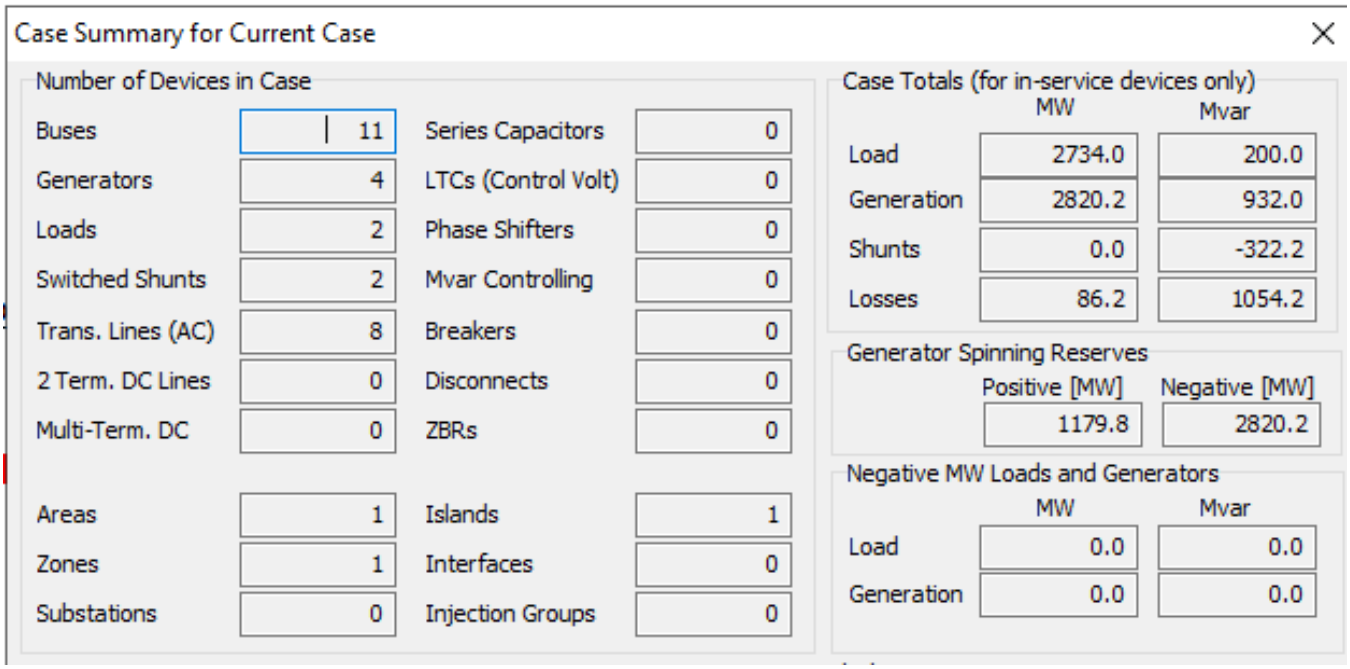


figure 17 case summary at tapings 0.95.

Further increasing the tapings beyond this point the voltage violation at buses increases. At taping value 1.12 there are 6 buses which violates the normal range of voltage. And finally a massive blackout occurs at taping ratio 1.15 as shown below.

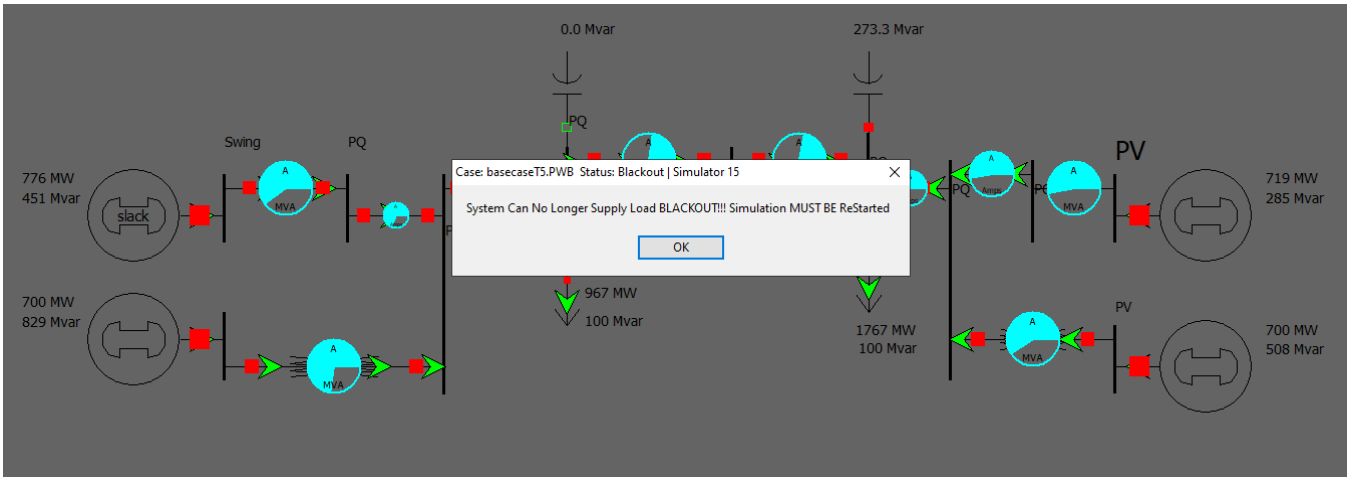


figure 18 blackout at transformer tapings 1.15.

Task 6: Removing the Shunt capacitor at bus 7 figure below.

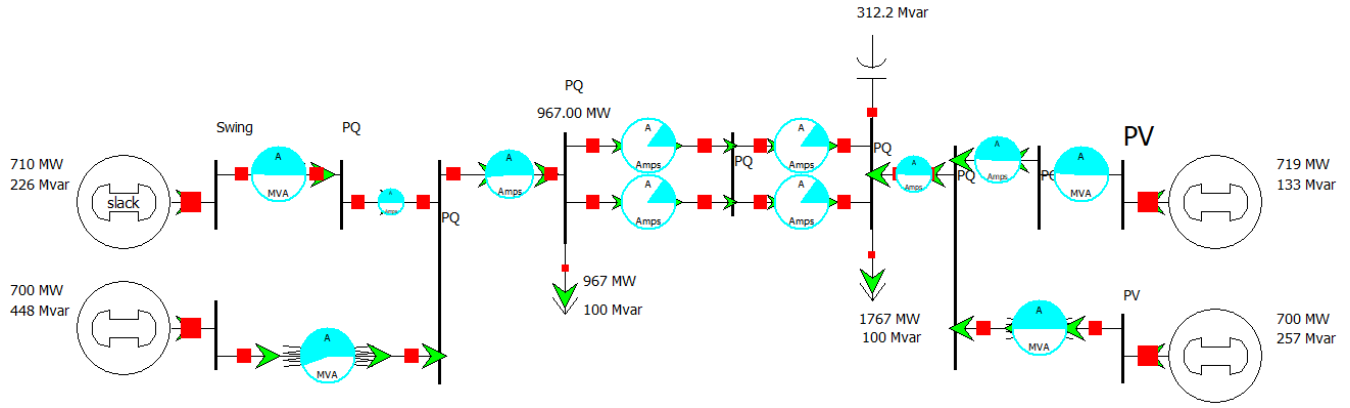


figure 19 Removal of capacitor bank at bus 7.

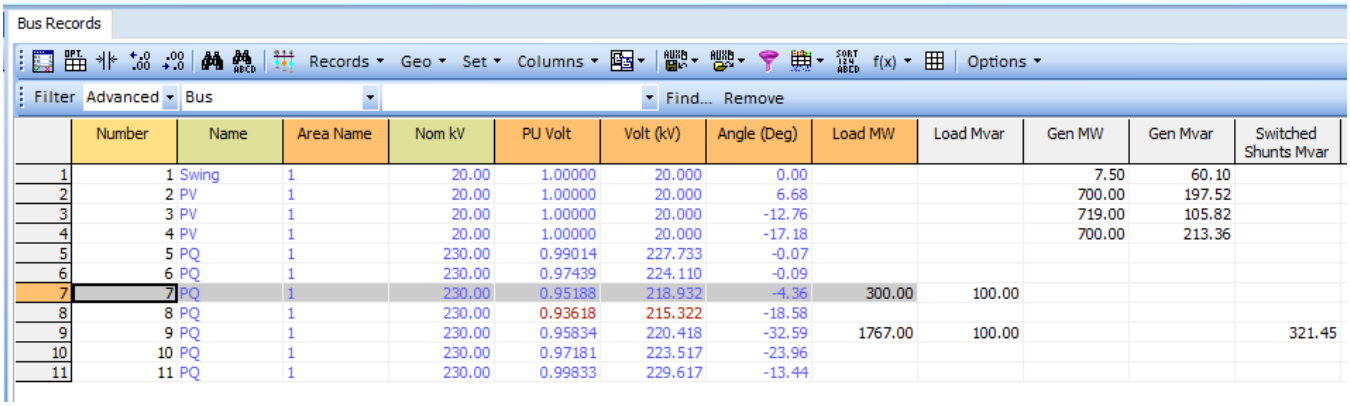
Result of bus voltages after removal of capacitor figure below.

Filter Advanced Bus Find... Remove

	Number	Name	Area Name	Nom kV	PU Volt	Volt (kV)	Angle (Deg)	Load MW	Load Mvar	Gen MW	Gen Mvar	Switched Shunts Mvar
1	1	Swing	1	20.00	1.00000	20.000	0.00			709.67	226.29	
2	2	PV	1	20.00	1.00000	20.000	-10.91			700.00	448.10	
3	3	PV	1	20.00	1.00000	20.000	-38.53			719.00	132.56	
4	4	PV	1	20.00	1.00000	20.000	-42.94			700.00	257.07	
5	5	PQ	1	230.00	0.96990	223.076	-6.89					
6	6	PQ	1	230.00	0.93360	214.727	-17.97					
7	7	PQ	1	230.00	0.89464	205.767	-27.36	967.00	100.00			
8	8	PQ	1	230.00	0.89521	205.899	-43.45					
9	9	PQ	1	230.00	0.94449	217.234	-58.55	1767.00	100.00			312.22
10	10	PQ	1	230.00	0.96470	221.880	-49.78					
11	11	PQ	1	230.00	0.99790	229.516	-39.20					

figure 20 bus voltages.

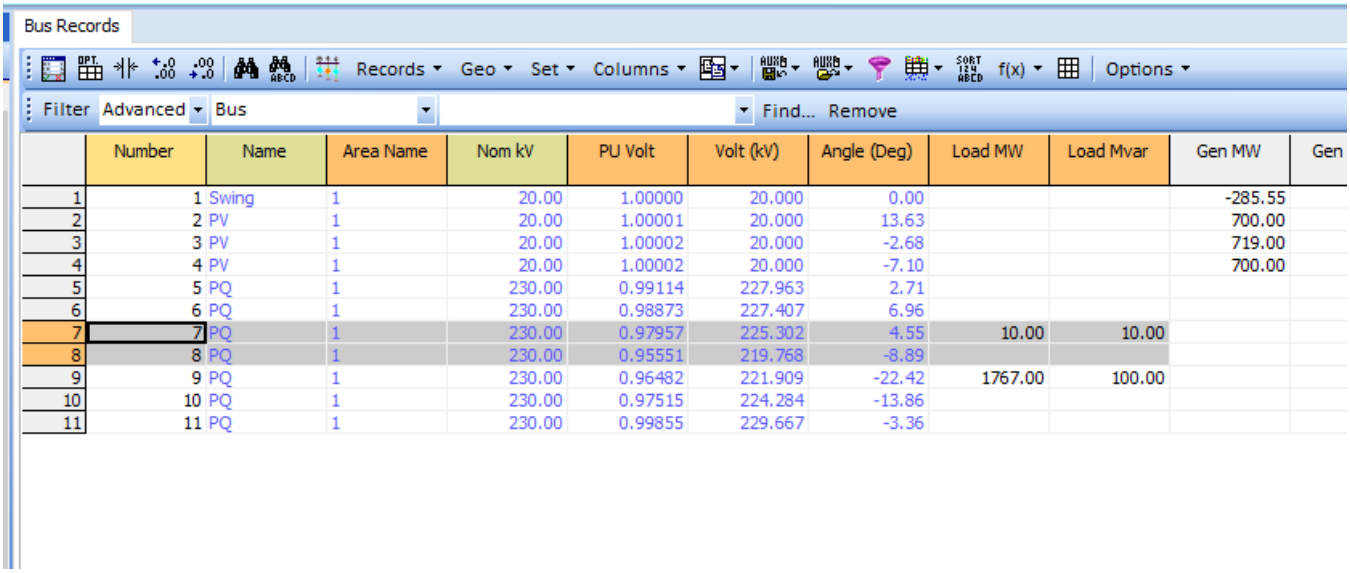
Decreasing the load from 967 MW to 300 MW at bus 7 we get the voltage in normal range clear from below figure.



	Number	Name	Area Name	Nom kV	PU Volt	Volt (kV)	Angle (Deg)	Load MW	Load Mvar	Gen MW	Gen Mvar	Switched Shunts Mvar
1	1	Swing	1	20.00	1.00000	20.000	0.00			7.50	60.10	
2	2	PV	1	20.00	1.00000	20.000	6.68			700.00	197.52	
3	3	PV	1	20.00	1.00000	20.000	-12.76			719.00	105.82	
4	4	PV	1	20.00	1.00000	20.000	-17.18			700.00	213.36	
5	5	PQ	1	230.00	0.99014	227.733	-0.07					
6	6	PQ	1	230.00	0.97439	224.110	-0.09					
7	7	PQ	1	230.00	0.95188	218.932	-4.36	300.00	100.00			
8	8	PQ	1	230.00	0.93618	215.322	-18.58					
9	9	PQ	1	230.00	0.95834	220.418	-32.59	1767.00	100.00			321.45
10	10	PQ	1	230.00	0.97181	223.517	-23.96					
11	11	PQ	1	230.00	0.99833	229.617	-13.44					

figure 21 Bus 7 data information.

Further decreasing the load to a very least value of 10MW & 10MVAR we get the normal range voltage (1.05-0.95) at bus 7,8 and all buses. figure below shows results of the simulation. On this load the slack bus generator starts consuming a large amount of power 285MW and acts as a motor(load).



	Number	Name	Area Name	Nom kV	PU Volt	Volt (kV)	Angle (Deg)	Load MW	Load Mvar	Gen MW	Gen
1	1	Swing	1	20.00	1.00000	20.000	0.00			-285.55	
2	2	PV	1	20.00	1.00001	20.000	13.63			700.00	
3	3	PV	1	20.00	1.00002	20.000	-2.68			719.00	
4	4	PV	1	20.00	1.00002	20.000	-7.10			700.00	
5	5	PQ	1	230.00	0.99114	227.963	2.71				
6	6	PQ	1	230.00	0.98873	227.407	6.96				
7	7	PQ	1	230.00	0.97957	225.302	4.55	10.00	10.00		
8	8	PQ	1	230.00	0.95551	219.768	-8.89				
9	9	PQ	1	230.00	0.96482	221.909	-22.42	1767.00	100.00		
10	10	PQ	1	230.00	0.97515	224.284	-13.86				
11	11	PQ	1	230.00	0.99855	229.667	-3.36				

figure 22 Buses values at 10MW & 10MVAR load at bus 7.

From difference case study huge difference at slack generator and bus 7 can be observed.

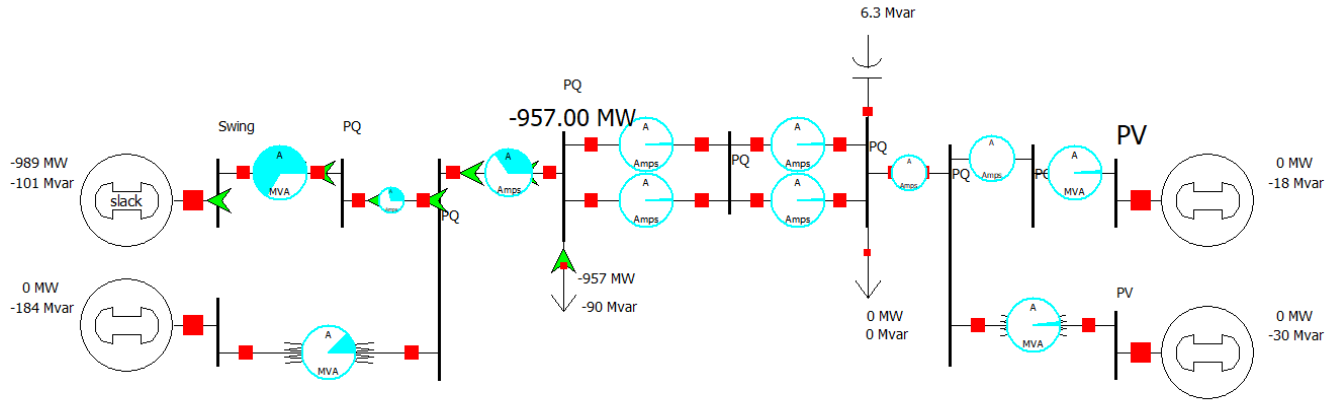


figure 23 Task 6 difference flow from base case.

Task 7: Losses or minimized up to 69MW by adjusting P=950MW at bus 7,8. Increasing or decreasing the value of P beyond this value the power loss increases as clear from below case summary in figure below.

Case Summary for Current Case

Number of Devices in Case

Buses	11	Series Capacitors	0
Generators	4	LTCs (Control Volt)	0
Loads	2	Phase Shifters	0
Switched Shunts	2	Mvar Controlling	0
Trans. Lines (AC)	8	Breakers	0
2 Term. DC Lines	0	Disconnects	0
Multi-Term. DC	0	ZBRs	0
Areas	1	Islands	1
Zones	1	Interfaces	0
Substations	0	Injection Groups	0

Case Totals (for in-service devices only)

	MW	Mvar
Load	2734.0	200.0
Generation	2803.3	553.8
Shunts	0.0	-517.1
Losses	69.3	870.9

Generator Spinning Reserves

Positive [MW]	Negative [MW]
1196.7	2803.3

Negative MW Loads and Generators

	MW	Mvar
Load	0.0	0.0
Generation	0.0	0.0

figure 24 Minimized losses.

Task 8: By increasing the generation of bus 2 by 100MW, the output of slack bus decreases by 100MW. By this way the power loss in power system is minimized by slack bus.

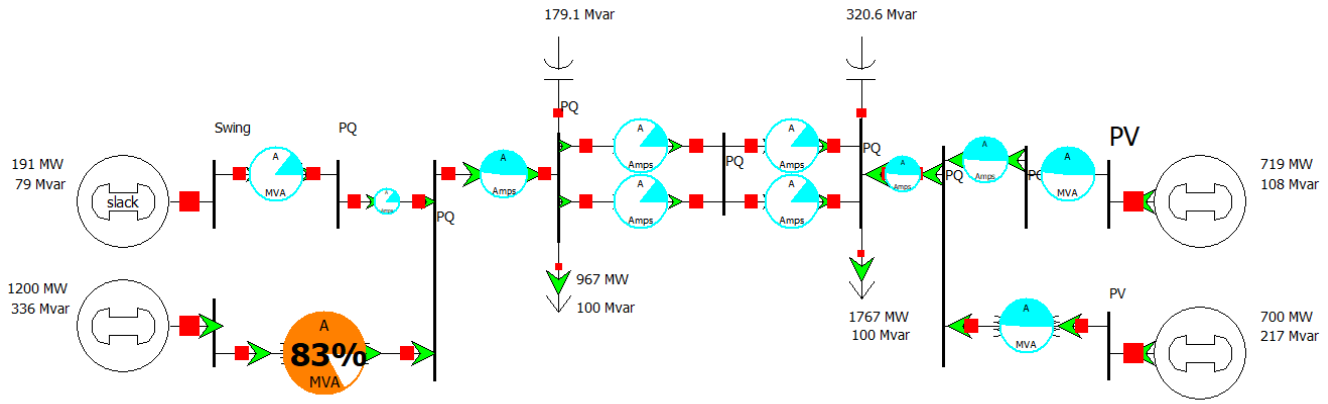


figure 25 Power output at slack bus(1) is 200MW & when bus 2=1200MW

Bus Records | Custom Case Information

Records | Geo | Set | Columns | Options

Filter: Advanced | Bus | Find... | Remove

	Number	Name	Area Name	Nom kV	PU Volt	Volt (kV)	Angle (Deg)	Load MW	Load Mvar	Gen MW	Gen Mvar	Switched Shunts Mvar	Act
1	1	Swing	1	20.00	1.00000	20.000	0.00			191.13	78.61		
2	2	PV	1	20.00	1.00000	20.000	7.18			1200.00	335.70		
3	3	PV	1	20.00	1.00000	20.000	-21.89			719.00	108.32		
4	4	PV	1	20.00	1.00000	20.000	-26.31			700.00	217.45		
5	5	PQ	1	230.00	0.98760	227.149	-1.82						
6	6	PQ	1	230.00	0.96522	222.001	-4.58						
7	7	PQ	1	230.00	0.94639	217.670	-13.24	967.00	100.00			179.13	
8	8	PQ	1	230.00	0.93232	214.434	-27.63						
9	9	PQ	1	230.00	0.95704	220.120	-41.73	1767.00	100.00			320.57	
10	10	PQ	1	230.00	0.97115	223.363	-33.10						
11	11	PQ	1	230.00	0.99829	229.607	-22.56						

figure 26 Generation at slack and bus 2.

The power loss is reduced by 12MW from base case as clear from below summary.

Case Summary for Current Case

Number of Devices in Case

Buses	11	Series Capacitors	0
Generators	4	LTCs (Control Volt)	0
Loads	2	Phase Shifters	0
Switched Shunts	2	Mvar Controlling	0
Trans. Lines (AC)	8	Breakers	0
2 Term. DC Lines	0	Disconnects	0
Multi-Term. DC	0	ZBRs	0
Areas	1	Islands	1
Zones	1	Interfaces	0
Substations	0	Injection Groups	0

Case Totals (for in-service devices only)

	MW	Mvar
Load	2734.0	200.0
Generation	2810.1	740.1
Shunts	0.0	-499.7
Losses	76.1	1039.8

Generator Spinning Reserves

Positive [MW]	Negative [MW]
1189.9	2810.1

Negative MW Loads and Generators

	MW	Mvar
Load	0.0	0.0
Generation	0.0	0.0

figure 27 power loss is reduced to 76MW

Conclusion; In this activity we analyze a power system of 11 buses using powerWorld simulator. We studied the effect of transmission line tripping, compensating bus voltages to bring it in normal range by using capacitor bank, effect of transformer tapings on voltage stability. Further we studied the positive effect of load shedding on voltage stability. And the role of slack bus in power system. Slack bus generates the power required by the system in order to reduce power losses.

References

[1] MathWorks, "MathWorks," MathWorks, [Online]. Available: https://www.mathworks.com/. [Accessed 3 December 2021].

[2] H. sadat, Power System Analysis, 1999.

[3] PowerWorldCorp, "Training: Editing and Analyzing an Existing Case," PowerWorld Corporation, [Online]. Available: https://www.youtube.com/user/PowerWorldCorp/playlists. [Accessed 2 December 2021].