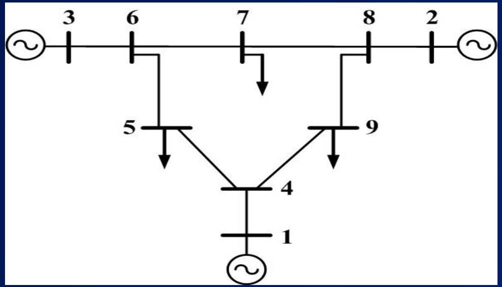
IEEE-9 BUS

Load Flow Analysis

Course Code: EE 308

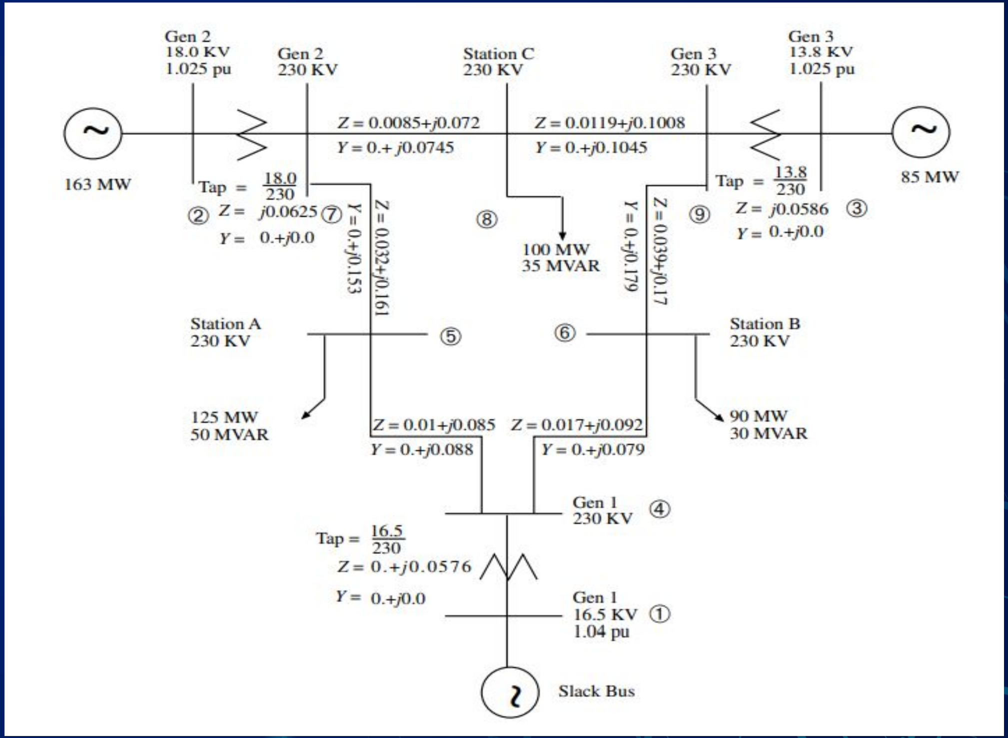
Comparison of different non-linear solution techniques in PowerWorld Simulator

IEEE 9 BUS SYSTEM



IEEE 9 bus system consists of 3 synchronous **generators**, nine buses, six transmission lines, three **transformers** & three P-Q loads. The interconnection of these devices is depicted in the figure.

We have performed **load flow analysis** to determine the **steady-state operating characteristics** of the power system for a given load and generator real power and voltage conditions.



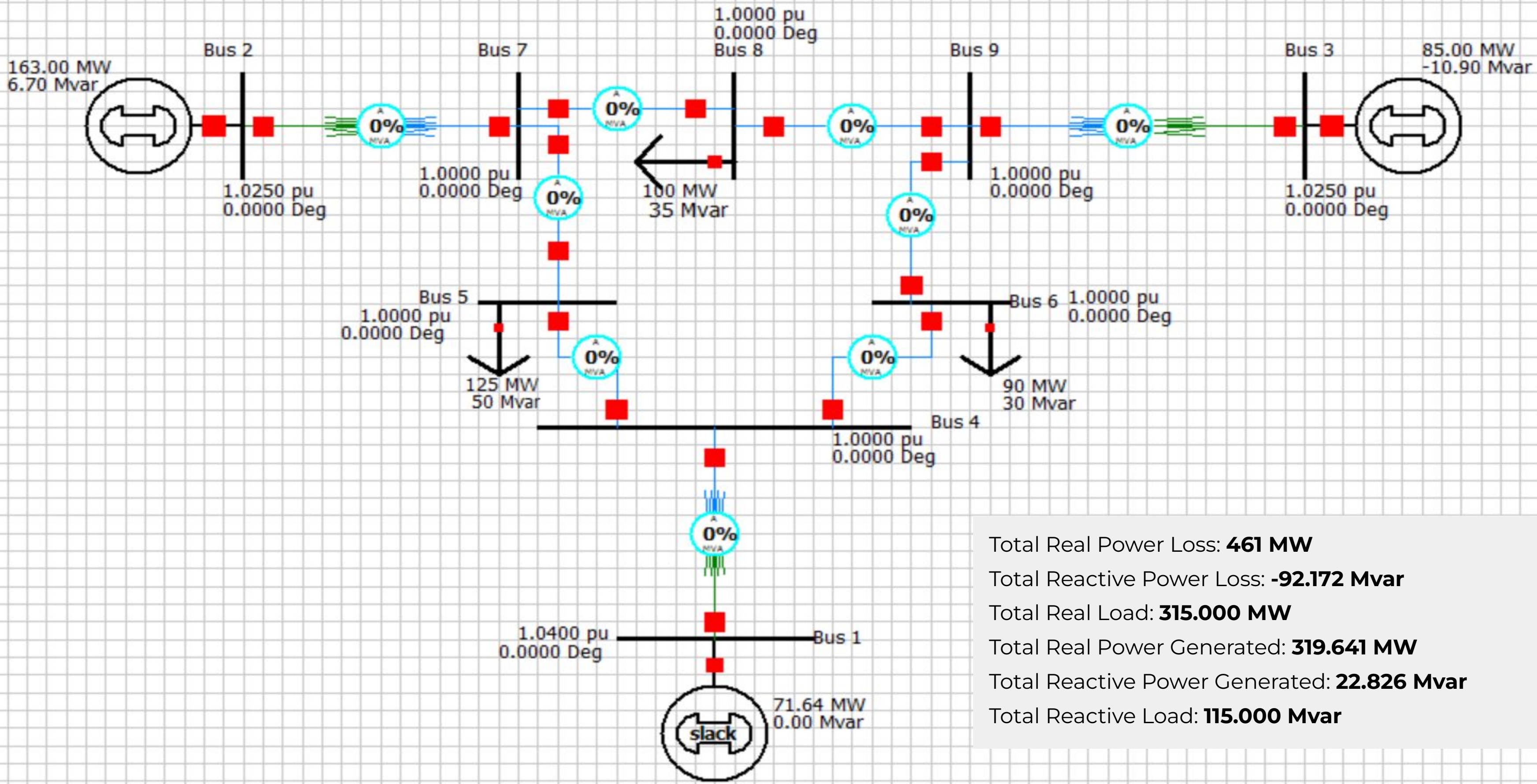
Bus data of the 9 bus system

Bus No.	Bus Type	Per unit Voltage	Voltage (KV)	Generation (MW)	Generation (Mvar)	Load(MW)	Load(Mvar)
1	Slack	1.04	16.5KV	0	0	0	0
2	PV	1.025	18.0KV	163	6.7	0	0
3	PV	1.025	13.8KV	85	-10.9	0	0
4	PQ	1	230KV	0	0	0	0
5	PQ	1	230KV	0	0	125	50
6	PQ	1	230KV	0	0	90	30
7	PQ	1	230KV	0	0	0	0
8	PQ	1	230KV	0	0	100	35
9	PQ	1	230KV	0	0	0	0

Line and branch data of the 9 bus system

Line From	Line To	R	X	B
1	4	0	0.0576	0
4	5	0.01	0.085	0.176
4	6	0.017	0.092	0.158
6	9	0.039	0.17	0.358
5	7	0.032	0.161	0.306
9	3	0	0.0586	0
7	2	0	0.0625	0
9	8	0.0119	0.1008	0.209
7	8	0.0085	0.072	0.149

IEEE-9 Bus simulation in PowerWorld



Total Real Power Loss: **461 MW**

Total Reactive Power Loss: **-92.172 Mvar**

Total Real Load: **315.000 MW**

Total Real Power Generated: **319.641 MW**

Total Reactive Power Generated: **22.826 Mvar**

Total Reactive Load: **115.000 Mvar**

Y Bus Matrix

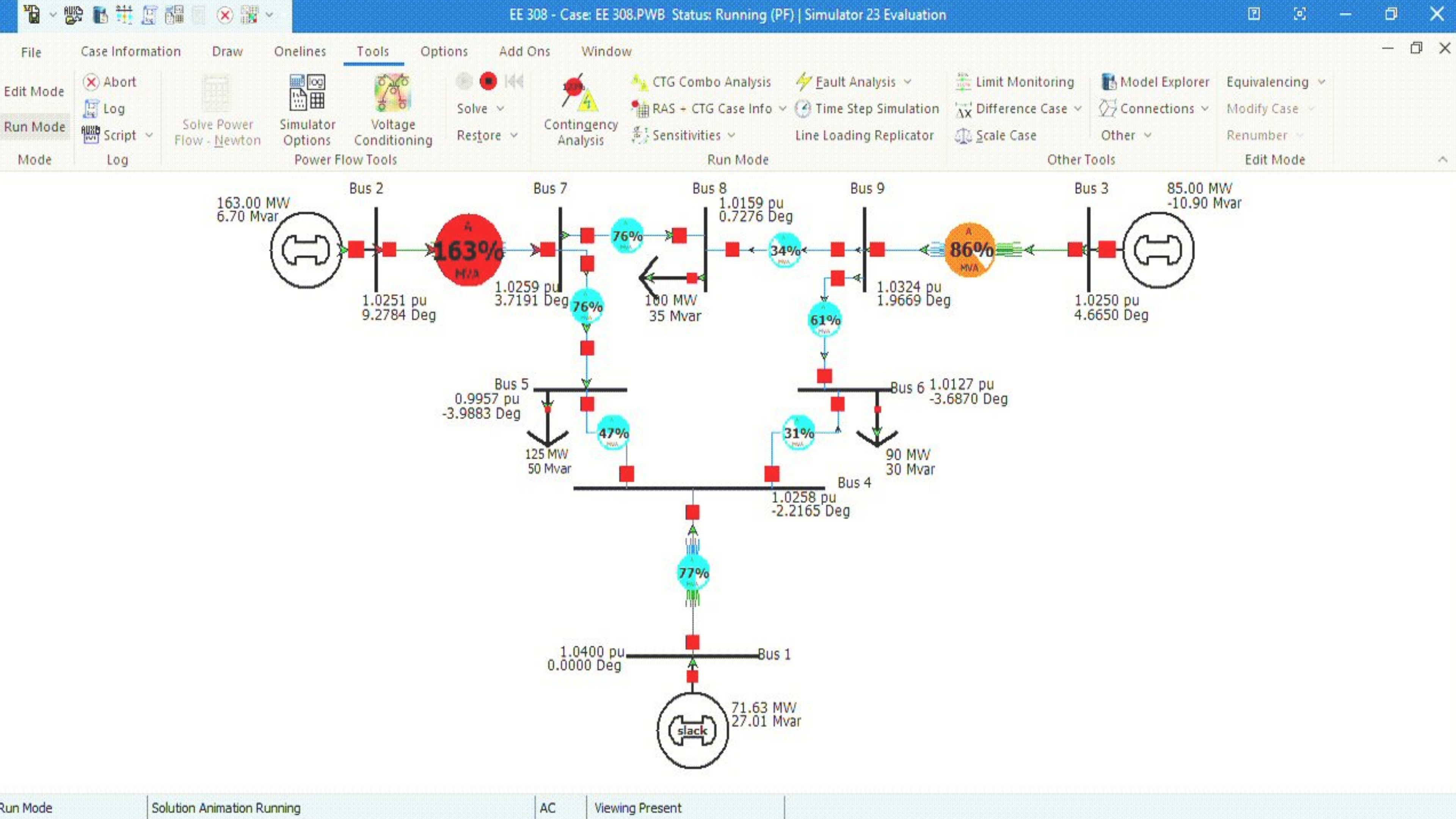
No.	Name	Bus1	Bus2	Bus3	Bus4	Bus5	Bus6	Bus7	Bus8	Bus9
1	Bus 1	0.00-j17.36	-	-	-0.00+j17.36	-	–	-	-	-
2	Bus 2	-	0.00-j16.00	-	-	-	-	-0.00+j16.00	-	-
3	Bus 3	-	-	0.00-j17.06	-	-	-	-	-	-0.00+j17.06
4	Bus 4	-0.00+j17.36	-	-	3.31-j39.31	-1.37+j11.60	-1.94+j10.51	-	-	-
5	Bus 5	-	-	-	-1.37+j11.60	2.55-j17.34	-	-1.19+j5.98	-	-
6	Bus 6	-	-	-	-1.94+j10.51	-	3.22-j15.84	-	-	-1.28+j5.59
7	Bus 7	-	-0.00+j16.00	-	-	-1.19+j5.98	-	2.80-j35.45	-1.62+j13.70	-
8	Bus 8	-	-	-	-	-	-	-1.62+j13.70	2.77-j23.30	-1.16+j9.78
9	Bus 9	-	-	-0.00+j17.06	-	-	-1.28+j5.59	-	-1.16+j9.78	2.44-j32.15

Load flow analysis

Load flow studies are performed on power system to understand the nature of the installed network. Load flow is used to determine the **static performance** of the system.

It is commonly used to investigate:

- **Component or circuit loading**
- **Bus voltage profiles (magnitude, phase angle, etc)**
- **Real and reactive power flow**
- **Power system losses**
- **Proper transformer tap settings**


EE 308 - Case: EE 308.PWB Status: Running (PF) | Simulator 23 Evaluation
File
Case Information
Draw
Onelines
Tools
Options
Add Ons
Window
Edit Mode
Run Mode
Mode
Abort
Log
Script
Log
Solve Power Flow - Newton
Simulator Options
Voltage Conditioning
Solve
Restore
Power Flow Tools
Contingency Analysis
CTG Combo Analysis
RAS + CTG Case Info
Sensitivities
Fault Analysis
Time Step Simulation
Line Loading Replicator
Run Mode
Limit Monitoring
Difference Case
Scale Case
Model Explorer
Connections
Other
Other Tools
Equivalencing
Modify Case
Renumber
Edit Mode
Bus 2
163.00 MW
6.70 Mvar
1.0251 pu
9.2784 Deg
163%
MVA
Bus 7
1.0259 pu
3.7191 Deg
76%
76%
Bus 8
1.0159 pu
0.7276 Deg
100 MW
35 Mvar
34%
Bus 9
1.0324 pu
1.9669 Deg
61%
86%
MVA
Bus 3
85.00 MW
-10.90 Mvar
1.0250 pu
4.6650 Deg
Bus 5
0.9957 pu
-3.9883 Deg
125 MW
50 Mvar
47%
Bus 6
1.0127 pu
-3.6870 Deg
31%
90 MW
30 Mvar
Bus 4
1.0258 pu
-2.2165 Deg
77%
1.0400 pu
0.0000 Deg
Bus 1
slack
71.63 MW
27.01 Mvar
Run Mode
Solution Animation Running
AC
Viewing Present

Load Flow Analysis for the 9 Bus System

Bus No.	Generation		Load		Bus Voltage	
	MW	Mvar	MW	Mvar	Voltage (p.u)	Angle(degree)
1	71.6	27	0	0	1.04	0
2	163	6.7	0	0	1.025	9.3
3	85	-10.9	0	0	1.025	4.7
4	0	0	0	0	1.026	-2.2
5	0	0	125	50	0.996	-4
6	0	0	90	30	1.013	-3.7
7	0	0	0	0	1.026	3.7
8	0	0	100	35	1.016	0.7
9	0	0	0	0	1.032	2

Line to Line Losses and Power Transfer Data

Line		P	Q	Line Loss	
From	To	MW	Mvar	MW	Mvar
1	4	70.53	27	0	3.23
4	5	40.88	22.9	0.3	-15.8
4	6	30.7	1	0.2	-15.43
6	9	59.6	-13.6	1.4	-31.5
5	7	84.3	-11.3	2.3	-19.8
9	3	85	15	0	4.1
7	2	163	9.1	0	15.8
9	8	24.2	3.1	0.1	-21.2
7	8	76.4	-0.8	0.5	-11.5

Gauss- Seidel Method

With the slack bus voltage assumed (usually V1 = 1.0 p.u.), the remaining **(n-1)** bus voltages are found through **iterative process** as follows

$$P_i = \sum_{j=1}^{n} |V_i||V_j||Y_{ij}|\cos(\theta_{ij} - \delta_i + \delta_j)$$

$$Q_i = -\sum_{j=1}^{n} |V_i||V_j||Y_{ij}|sin(\theta_{ij} - \delta_i + \delta_j)$$

The equation 1 and 2 are called static load flow equations.

$$I_i = \frac{P_i - jQ_i}{V_i^*}$$

$$V_i = \frac{1}{Y_{ii}}\left(I_i - \sum_{\substack{j=1 \\ j\neq 1}}^{n} Y_{ij}V_j\right) \quad i = 2,3,4\ldots n$$

For $(k+1)^{\text{th}}$ iteration, the voltage equation becomes

$$V_i^{(k+1)} = \frac{1}{Y_{ii}}\left[\frac{P_i - jQ_i}{(V_i^k)^*} - \sum_{j=1}^{i-1}(Y_{ij}\, V_j^{k+1}) - \sum_{j=i+1}^{n}(Y_{ij}V_j^k)\right]$$

Newton- Raphson method

- The **Jacobian matrix** gives the linearized relationship between small changes in voltage angle $\Delta\delta$ and voltage magnitude ΔV with the small changes in **active and reactive power ΔP and ΔQ.**
- The terms **ΔPir and ΔQir** are the difference between the scheduled and calculated valued, known as **mismatch** vector or power residuals, given by

$$P_i\,(\text{scheduled}) - P_i^r\ \text{calculated} = \Delta P_i^r$$

$$Q_i\,(\text{scheduled}) - Q_i^r\ \text{calculated} = \Delta Q_i^r$$

$$|V|^{(r+1)} = |V|^r + |\Delta V|^r$$

$$\begin{bmatrix}\Delta P\\ \Delta Q\end{bmatrix} = [\,\mathrm{J}\,]\begin{bmatrix}\Delta\delta\\ \Delta V\end{bmatrix}$$

$$\delta(r+1) = \delta\, r + \Delta\delta\, r$$

$$\text{here } [\mathrm{J}] = \begin{bmatrix}\mathrm{J1} & \mathrm{J2}\\ \mathrm{J3} & \mathrm{J4}\end{bmatrix}$$

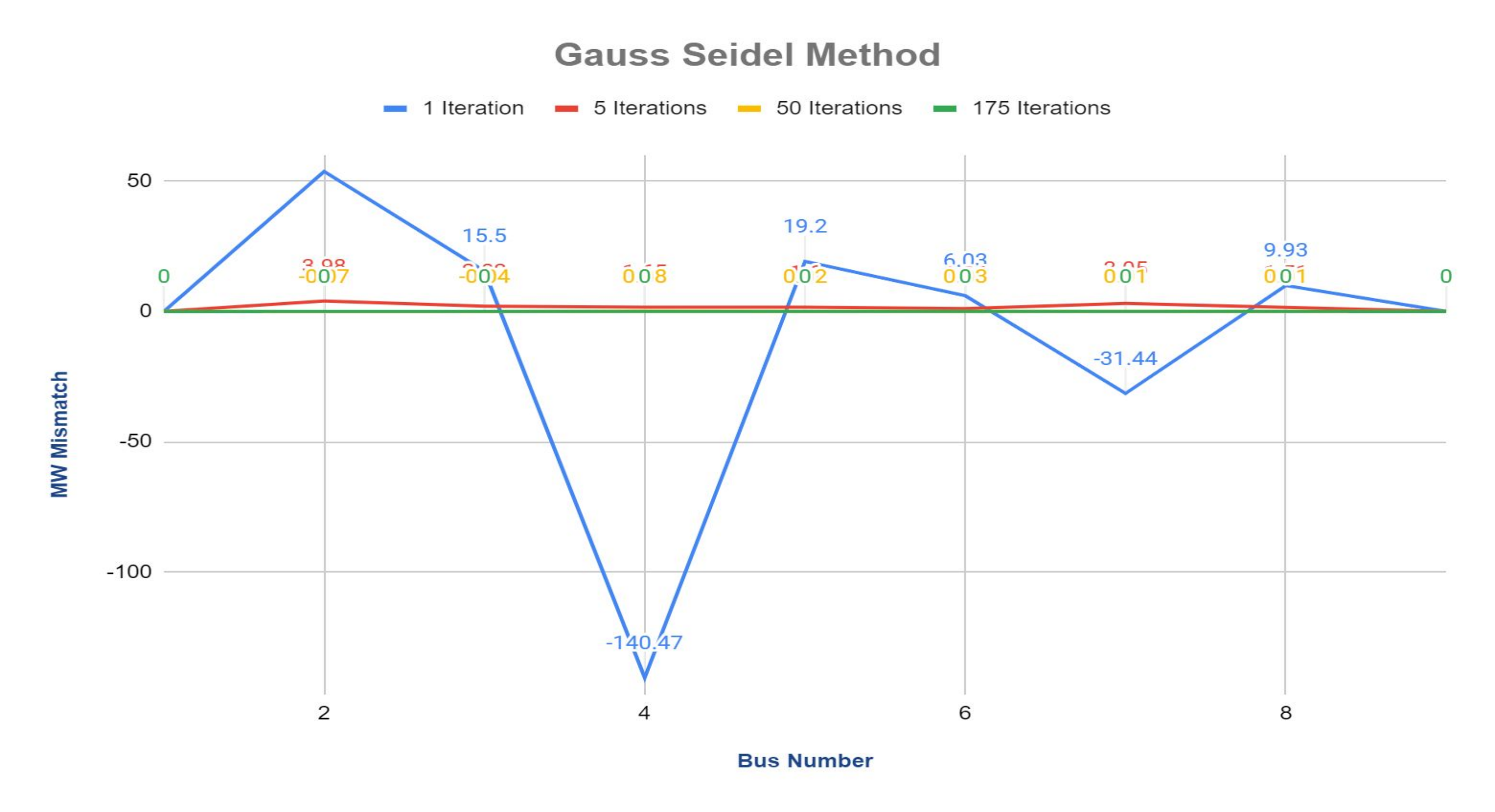
where r = no. of iteration

Initial Mismatches (Flat Start)

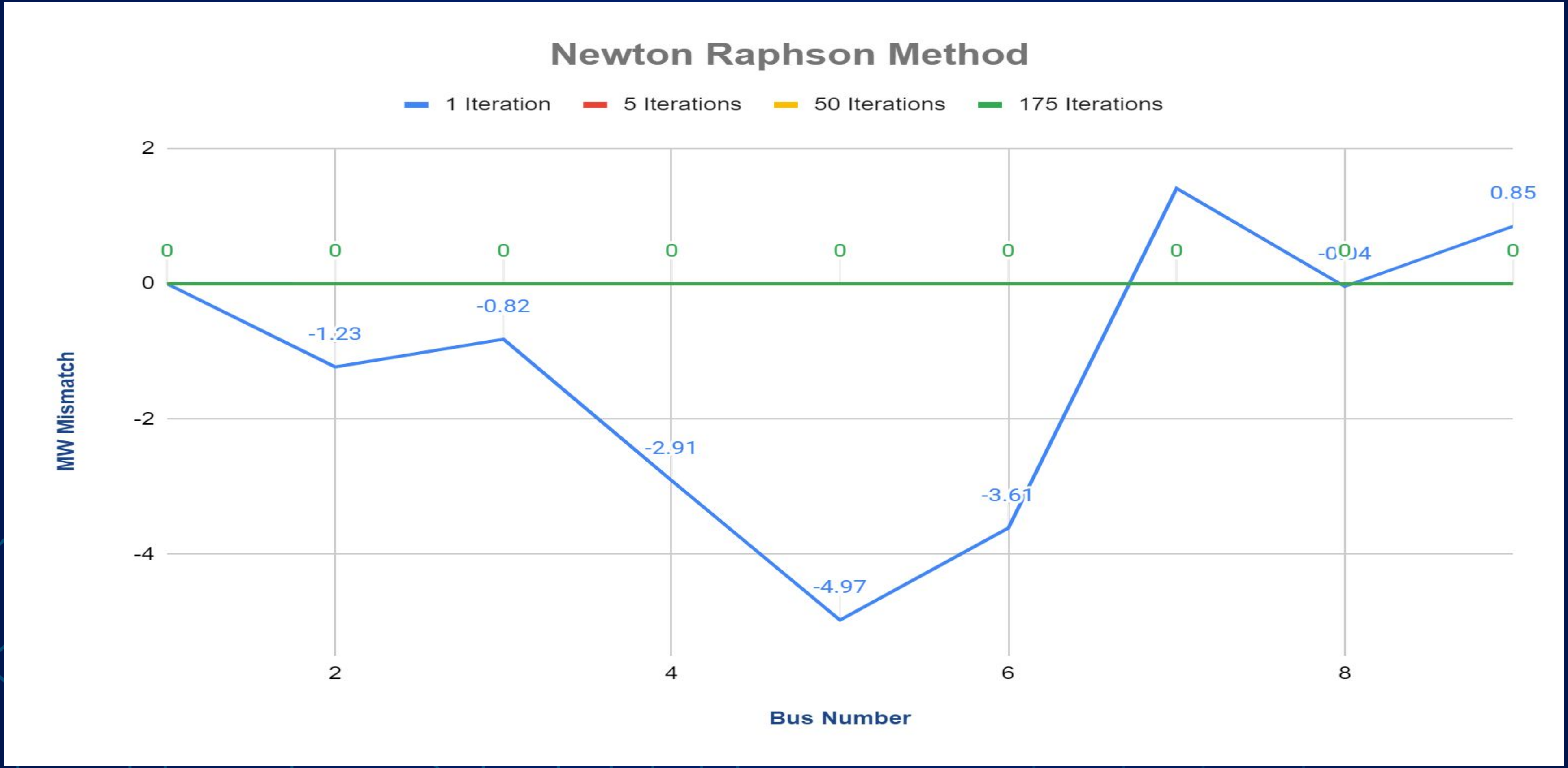
	Number	Name	Area Name	Mismatch MW	Mismatch Mvar	Mismatch MV
1	2	Bus 2	1	163.00	6.70	163.14
2	5	Bus 5	1	-125.00	-25.90	127.66
3	8	Bus 8	1	-100.00	-17.10	101.45
4	6	Bus 6	1	-90.00	-4.20	90.10
5	4	Bus 4	1	0.00	86.14	86.14
6	3	Bus 3	1	85.00	-10.90	85.70
7	9	Bus 9	1	0.00	28.35	28.35
8	7	Bus 7	1	0.00	22.75	22.75
9	1	Bus 1	1	0.00	0.00	0.00

Number of Iterations	Bus Number	Gauss Seidel			Newton Raphson		
		MW Mismatch	Mvar Mismatch	MVA Mismatch	MW Mismatch	Mvar Mismatch	MVA Mismatch
1	1	0	0	0	0	0	0
	2	53.69	18.51	56.79	-1.23	-21.18	21.21
	3	15.5	2.59	15.71	-0.82	-5.35	5.41
	4	-140.47	-0.15	140.47	-2.91	4.17	5.08
	5	19.2	-2.88	19.41	-4.97	-8.31	9.68
	6	6.03	2.7	6.61	-3.61	-5.03	6.19
	7	-31.44	-12.57	33.86	1.41	-0.53	1.51
	8	9.93	5.9	11.55	-0.04	0.22	0.22
	9	0	0	0	0.85	-0.62	1.05
5	1	0	0	0	0	0	0
	2	3.98	8.28	9.18	0	-0.01	0.01
	3	2.02	-7.28	7.55	0	0	0
	4	1.65	1.06	1.96	0	0	0
	5	1.6	-0.08	1.6	0	0	0
	6	1.06	0.88	1.38	0	0	0
	7	3.05	1.94	3.61	0	0	0
	8	1.51	1.8	2.35	0	0	0
	9	0	0	0	0	0	0
50	1	0	0	0	0	0	0
	2	-0.07	7.02	7.02	0	-0.01	0.01
	3	-0.04	-10.58	10.58	0	0	0
	4	0.08	0.27	0.28	0	0	0
	5	0.02	0.12	0.12	0	0	0
	6	0.03	0.1	0.11	0	0	0
	7	0.01	0.28	0.28	0	0	0
	8	0.01	0.18	0.18	0	0	0
	9	0	0	0	0	0	0
175	1	0	0	0	0	0	0
	2	0	6.7	6.7	0	-0.01	0.01
	3	0	-10.9	10.9	0	0	0
	4	0	0	0	0	0	0
	5	0	0	0	0	0	0
	6	0	0	0	0	0	0
	7	0	0	0	0	0	0
	8	0	0	0	0	0	0
	9	0	0	0	0	0	0

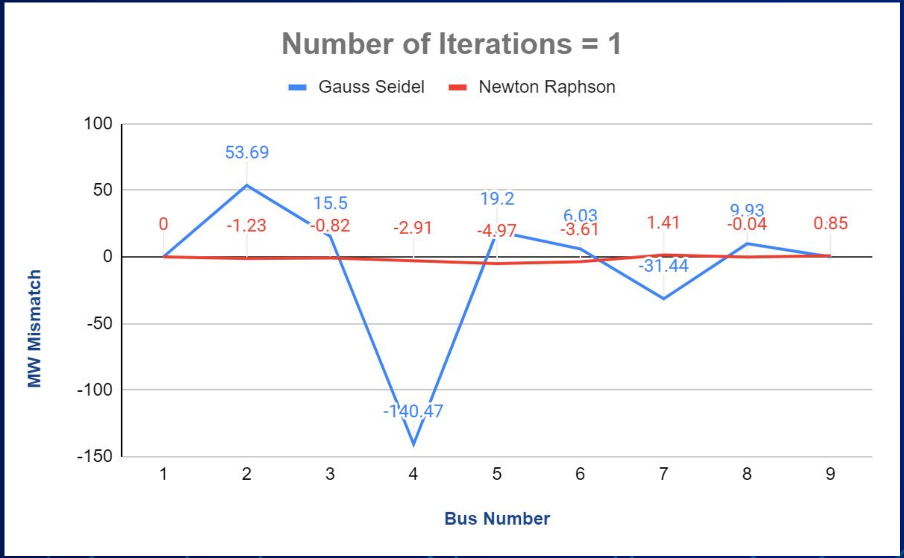
Comparing the results

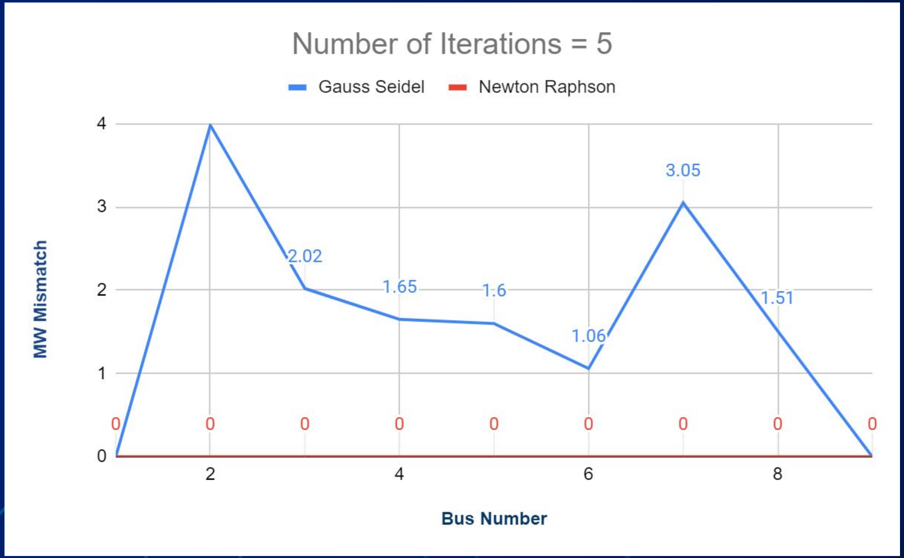


Comparing the results



Comparing the results





Observations

The **Gauss-Siedel** method requires more iterations to converge for the same values of |V|, angle, active and reactive power. Furthermore, with less iterations, the **Newton Raphson** approach outperforms the **GS** method.

The **results** show that the **Gauss-Siedel** approach is straightforward and easy to implement, but gets slower as the number of buses **increases**. The **Newton Raphson** approach is more accurate than any other methods and yields better results in fewer iterations.

Method Used→ Bus No.↓	Gauss-Siedel Method	Newton - Raphson method
6	24	11
9	182	11
14	384	7
30	648	5
57	864	11

System Data Changes

The following alterations are made on the IEEE 9 Standard Bus System model

Loads:

Load on Bus 5 is changed to **50 MW, 0 MVAR**
Load on Bus 6 is changed to **150 MW, 50 MVAR**
Load on Bus 8 is changed to **200 MW, 50 MVAR**

Generators:

Real and Reactive Power of all generators are made equal to **500MW** and **10MVAR**

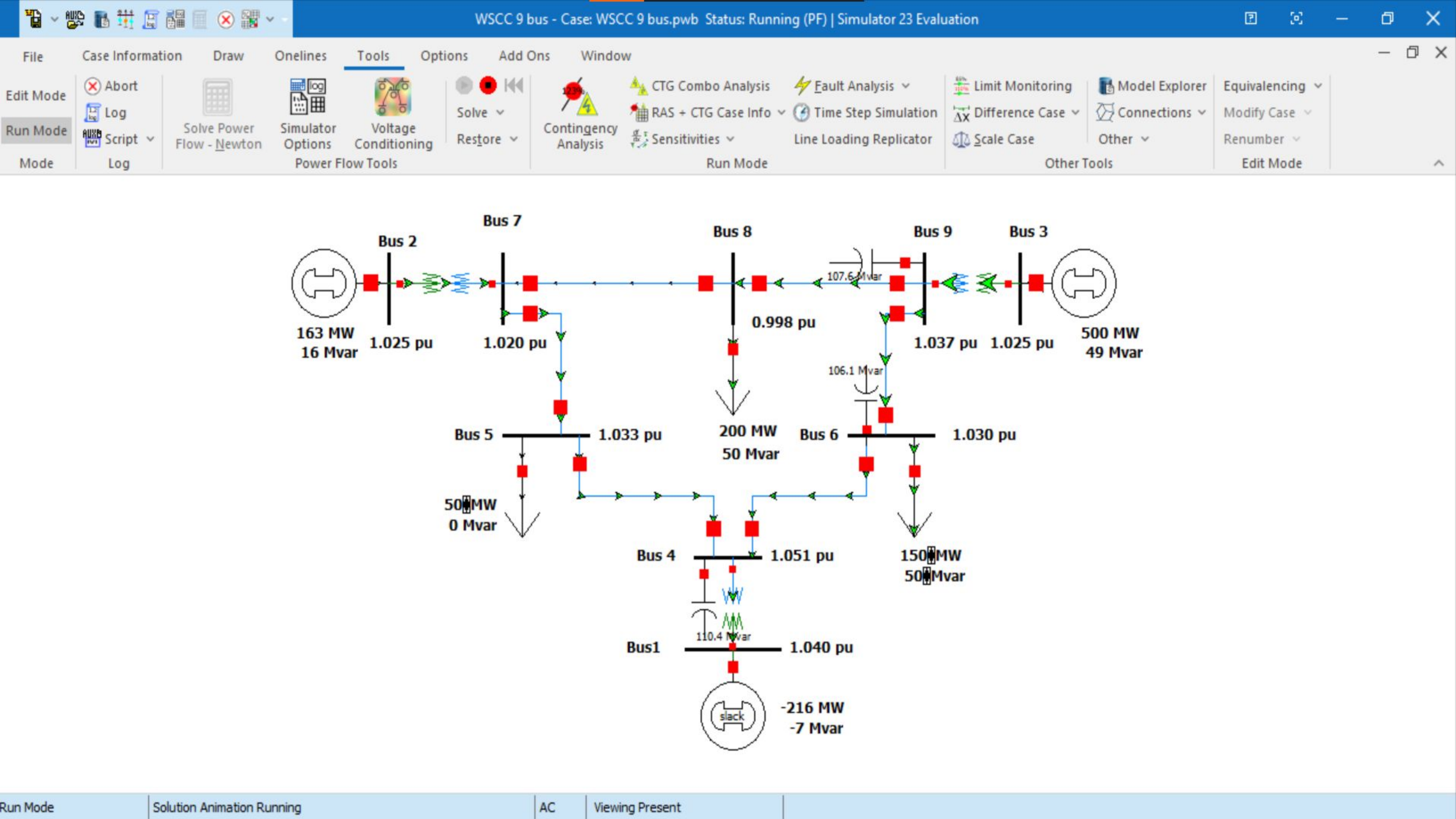
Under normal system conditions the voltages need to be maintained between **95% and 105%** of the nominal

Low Voltage condition results in equipment malfunctions:

- Load will stall, overheat or damage
- Reactive power output of capacitor is exponentially reduced
- Generating units may trip

Here, Per Unit Voltage of Bus 6 = 0.82053

	Number	Name	Area Name	Nom kV	PU Volt	Volt (kV)	Angle (Deg)	Load MW	Load Mvar	Gen MW	Gen Mvar
1	1	Bus1	1	16.50	1.04000	17.160	0.00			-201.03	201.05
2	2	Bus 2	1	18.00	1.02500	18.450	37.66			163.00	103.93
3	3	Bus 3	1	13.80	1.02501	14.145	66.67			500.00	242.18
4	4	Bus 4	1	230.00	0.93530	215.119	6.84				
5	5	Bus 5	1	230.00	0.92766	213.362	12.58	50.00	0.00		
6	6	Bus 6	1	230.00	0.82053	188.722	13.99	150.00	50.00		
7	7	Bus 7	1	230.00	0.96675	222.354	31.76				
8	8	Bus 8	1	230.00	0.91805	211.151	33.10	200.00	50.00		
9	9	Bus 9	1	230.00	0.93149	214.243	48.80				


WSCC 9 bus - Case: WSCC 9 bus.pwb Status: Running (PF) | Simulator 23 Evaluation
File
Case Information
Draw
Onelines
Tools
Options
Add Ons
Window
Edit Mode
Run Mode
Mode
Abort
Log
Script
Log
Solve Power Flow - Newton
Simulator Options
Voltage Conditioning
Solve
Restore
Power Flow Tools
Contingency Analysis
CTG Combo Analysis
RAS + CTG Case Info
Sensitivities
Fault Analysis
Time Step Simulation
Line Loading Replicator
Run Mode
Limit Monitoring
Difference Case
Scale Case
Model Explorer
Connections
Other
Other Tools
Equivalencing
Modify Case
Renumber
Edit Mode
Bus 2
Bus 7
Bus 8
Bus 9
Bus 3
107.6 Mvar
163 MW
16 Mvar
1.025 pu
1.020 pu
0.998 pu
1.037 pu
1.025 pu
500 MW
49 Mvar
106.1 Mvar
Bus 5
1.033 pu
200 MW
50 Mvar
Bus 6
1.030 pu
50 MW
0 Mvar
Bus 4
1.051 pu
150 MW
50 Mvar
110.4 Mvar
Bus1
1.040 pu
slack
-216 MW
-7 Mvar
Run Mode
Solution Animation Running
AC
Viewing Present

Shunt Capacitor is Installed

- When Capacitor of **100MVar** rating is connected at **Bus 6 , Bus 9 and Bus 4**
- This leads to **per unit Voltage correction**
- Now, Per Unit Voltage of Bus 6 = **1.02999**

Buses | Mismatches | Ybus | Generators | OPF Buses | Mismatches

Records Geo Set Columns Options

Filter Advanced Bus Find... Remove Quick Filter

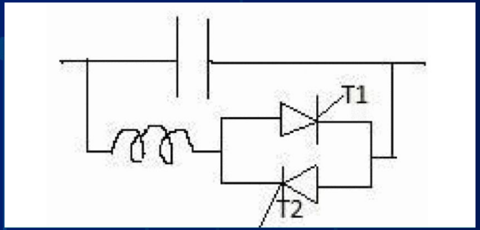
	Number	Name	Area Name	Nom kV	PU Volt	Volt (kV)	Angle (Deg)	Load MW	Load Mvar	Gen MW	Gen Mvar
1	1	Bus1	1	16.50	1.04000	17.160	0.00			-215.63	-7.11
2	2	Bus 2	1	18.00	1.02501	18.450	32.23			163.00	15.74
3	3	Bus 3	1	13.80	1.02503	14.145	55.14			500.00	48.72
4	4	Bus 4	1	230.00	1.05075	241.671	6.53				
5	5	Bus 5	1	230.00	1.03271	237.524	10.87	50.00	0.00		
6	6	Bus 6	1	230.00	1.02999	236.897	11.94	150.00	50.00		
7	7	Bus 7	1	230.00	1.02026	234.660	26.64				
8	8	Bus 8	1	230.00	0.99791	229.518	27.21	200.00	50.00		
9	9	Bus 9	1	230.00	1.03733	238.586	39.15				

Need for capacitor

The generation of **reactive power** affects the total generation cost due to increase in the transmission losses.

TCSC (Thyristor controlled series capacitor) introduces a number of important benefits:

- Sub synchronous resonance risks elimination
- Real power oscillations damping
- Improvement in post contingency stability
- Increased power flow through the lines



TCSC provides a cost effective alternative capable of boosting the degree of overall power flow.

Utilization of TCSC in real world power problems between any buses can help overcome the issues of **reactive power losses** and poor power quality.

Conclusion

Thus we have performed the load flow analysis of IEEE-9 Bus system by:

- Simulating the IEEE-9 Bus system on powerWorld simulator.
- Analysing the Gauss-Seidel and Newton-Raphson methods.
- Comparing the results of both these methods.
- Finding methods to improve the overall performance of the system.

Resources

- https://www.pscad.com/knowledge-base/article/25
- https://ieeexplore.ieee.org/document/8358277
- https://www.ripublication.com/irph/ijee16/ijeev9n2_01.pdf
- https://www.omazaki.co.id/en/load-flow-study-analysis/
- https://scholarworks.calstate.edu/downloads/xg94hv83w
- https://www.powerworld.com/WebHelp/Content/MainDocumentation_HTML/Limit_Monitoring_Settings_and_Limit_Violations_Dialog.htm
- https://www.researchgate.net/publication/338345486_Power_Flow_Analysis_using_Power_World_Simulator
- https://www.irjet.net/archives/V3/i3/IRJET-V3I323.pdf
- https://www.powerworld.com/files/12Weber_DFACTS.pdf

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Thank you