16:332:599:02 – Smart Grid
Project Report

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Contents

List of Figures

List of Tables

1 Case Study/Problem Formulation

For the single-line diagram in Figure 4 convert all positive-sequence impedance, load, and voltage data to per unit using the given system base quantities. Run the power flow program and obtain the bus, line, and transformer input/output voltages

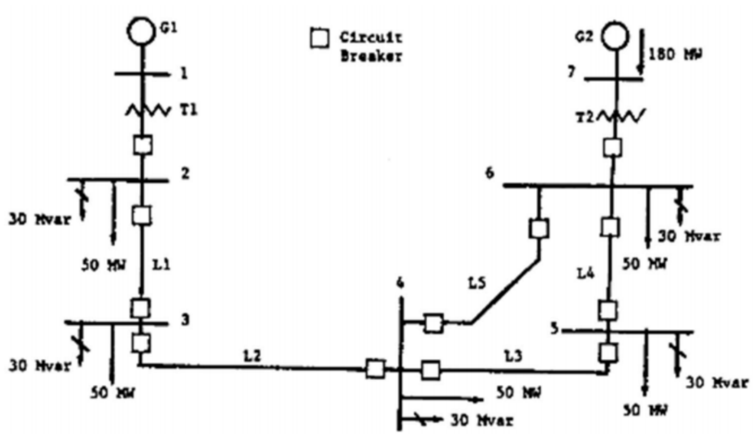


Figure 1: Original Circuit

Generator Ratings	
G1	$100MVA$, $13.8kV$, $x'' = 0.12$
G2	$200MVA$, $15.0kV$, $x'' = 0.12$
The generator neutrals are solidly grounded	

Transformer Ratings	
T1	$100MVA$, $13.8kV\Delta/230kVY$, $x = 0.1$ per unit
T2	$200MVA$, $15kV\Delta/230kVY$, $x = 0.1$ per unit
The transformer neutrals are solidly grounded	

Transmission Line Ratings	
All Lines	$230kV$, $z_1 = 0.08 + j0.5\Omega/km$, $y_1 = j3.3E-6S/km$, $Max\ MVA = 400$
Line Lengths	$L_1 = 15km$, $L_2 = 20km$, $L_3 = 40km$, $L_4 = 15km$, $L_5 = 50km$

Power Flow Data	
Bus 1	Swing bus $V_1 = 13.8kV$, $\partial_1 = 0°$
Bus 2, 3, 4, 5, 6	Load buses
Bus 7	Constant voltage magnitude bus, $V_7 = 15kV$, $P_{G7} = 180MW$, $-87MVAr < Q_{G7} < +87MVAr$

System Base Quantities
$S_{base} = 100MVA$ (three-phase)
$V_{base} = 13.8kV$ (line-to-line) in the zone of G_1

Table 1: Circuit Values

2 Detailed Solution

2.1 Calculating Per Unit Values

$$per\ unit\ (pu)\ value = \frac{Actual\ value}{Base\ value}$$

In zone $G1$, base values are,

$$S_{base} = 100MVA$$

$$V_{base_{L-L}} = 13.8kV$$

@ $G1$

$$S_{G1_{(pu)}} = \frac{100MVA}{100MVA} = \boxed{1pu}$$

$$V_{G1_{(pu)}} = \frac{13.8kV}{13.8kV} = \boxed{1pu}$$

$$x''_{(new)} = \boxed{0.12pu}$$

@ $T1$

$$S_{T1_{(pu)}} = \frac{100MVA}{100MVA} = \boxed{1pu}$$

$$V_{T1_{(pu)}} = \frac{13.8kV}{13.8kV} = \boxed{1pu}$$

$$x_{(pu)} = \boxed{0.1pu}$$

@ Bus 2

$$Q_{Load} = 30MVAr$$

$$Q_{Load_{(pu)}} = \frac{30MVAr}{100MVA} = \boxed{0.3pu}$$

$$P_{Load} = 50MW$$

$$P_{Load_{(pu)}} = \frac{50MW}{100MVA} = \boxed{0.5pu}$$

@ L_1

$$L_1 = 15km$$

$$z = 0.08 + j0.5\Omega/km$$

$$Z_{total} = (15km)(0.08 + j0.5\Omega/km) = \boxed{1.2 + j7.5\Omega}$$

$$\theta = tan^{-1}\left(\frac{7.5}{1.2}\right) = \boxed{80.91^\circ}$$

$$|Z_{total}| = \sqrt{(1.2)^2 + (7.5)^2} = \boxed{7.59539\Omega}$$

$$Z_{total} = \boxed{7.59539\angle 80.91°\Omega}$$

$$Z_{total_{(pu)}} = 7.595 \cdot \left(\frac{100MVA}{(230kV)^2}\right) = \boxed{0.014358pu}$$

@ Bus 3

$$Q_{Load} = 30MVAr$$

$$Q_{Load_{(pu)}} = \frac{30MVAr}{100MVA} = \boxed{0.3pu}$$

$$P_{Load} = 50MW$$

$$P_{Load_{(pu)}} = \frac{50MW}{100MVA} = \boxed{0.5pu}$$

@ Bus 4

$$Q_{Load} = 30MVAr$$

$$Q_{Load_{(pu)}} = \frac{30MVAr}{100MVA} = \boxed{0.3pu}$$

$$P_{Load} = 50MW$$

$$P_{Load_{(pu)}} = \frac{50MW}{100MVA} = \boxed{0.5pu}$$

@ Bus 5

$$Q_{Load} = 30MVAr$$

$$Q_{Load_{(pu)}} = \frac{30MVAr}{100MVA} = \boxed{0.3pu}$$

$$P_{Load} = 50MW$$

$$P_{Load_{(pu)}} = \frac{50MW}{100MVA} = \boxed{0.5pu}$$

@ Bus 6

$$Q_{Load} = 30MVAr$$

$$Q_{Load_{(pu)}} = \frac{30MVAr}{100MVA} = \boxed{0.3pu}$$

$$P_{Load} = 50MW$$

$$P_{Load_{(pu)}} = \frac{50MW}{100MVA} = \boxed{0.5pu}$$

@ L_2

$$L_2 = 20km$$

$$z = 0.08 + j0.5\Omega/km$$

$$Z_{total} = (20km)(0.08 + j0.5\Omega/km) = \boxed{1.6 + j10\Omega}$$

$$\theta = tan^{-1}\left(\frac{10}{1.6}\right) = \boxed{80.91°}$$

$$|Z_{total}| = \sqrt{(1.6)^2 + (10)^2} = \boxed{10.127191\Omega}$$

$$Z_{total} = \boxed{10.127191\angle 80.91°\Omega}$$

$$Z_{total_{(pu)}} = 10.127191 \cdot \left(\frac{100MVA}{(230kV)^2}\right) = \boxed{0.019144pu}$$

@ L_3

$$L_3 = 40km$$

$$z = 0.08 + j0.5\Omega/km$$

$$Z_{total} = (40km)(0.08 + j0.5\Omega/km) = \boxed{3.2 + j20\Omega}$$

$$\theta = tan^{-1}\left(\frac{20}{3.2}\right) = \boxed{80.91°}$$

$$|Z_{total}| = \sqrt{(3.2)^2 + (20)^2} = \boxed{20.254382\Omega}$$

$$Z_{total} = \boxed{20.254382\angle 80.91°\Omega}$$

$$Z_{total_{(pu)}} = 20.254382 \cdot \left(\frac{100MVA}{(230kV)^2}\right) = \boxed{0.038288pu}$$

@ L_4

$$L_4 = 15km$$

$$z = 0.08 + j0.5\Omega/km$$

$$Z_{total} = (15km)(0.08 + j0.5\Omega/km) = \boxed{1.2 + j7.5\Omega}$$

$$\theta = tan^{-1}\left(\frac{7.5}{1.2}\right) = \boxed{80.91°}$$

$$|Z_{total}| = \sqrt{(1.2)^2 + (7.5)^2} = \boxed{7.59539\Omega}$$

$$Z_{total} = \boxed{7.59539\angle 80.91°\Omega}$$

$$Z_{total_{(pu)}} = 7.595 \cdot \left(\frac{100MVA}{(230kV)^2}\right) = \boxed{0.014358pu}$$

@ L_5

$$L_5 = 50km$$

$$z = 0.08 + j0.5\Omega/km$$

$$Z_{total} = (50km)(0.08 + j0.5\Omega/km) = \boxed{4 + j25\Omega}$$

$$\theta = tan^{-1}\left(\frac{25}{4}\right) = \boxed{80.91°}$$

$$|Z_{total}| = \sqrt{(4)^2 + (25)^2} = \boxed{25.317978\Omega}$$

$$Z_{total} = \boxed{25.317978\angle 80.91°\Omega}$$

$$Z_{total_{(pu)}} = 25.317978 \cdot \left(\frac{100MVA}{(230kV)^2}\right) = \boxed{0.04786pu}$$

@ Bus 7

$$P_{G7_{(pu)}} = \frac{180MW}{100MVA} = \boxed{1.8pu}$$

$$\frac{-87MVAr}{100} < Q_{G7_{(pu)}} < \frac{87MVAr}{100}$$

$$-0.87pu < Q_{G7_{(pu)}} < 0.87pu$$

$$V_{T2_{(pu)}} = \frac{15kV}{13.8kV} = \boxed{1.086956pu}$$

2.1.1 Per-Unit One-Line Model

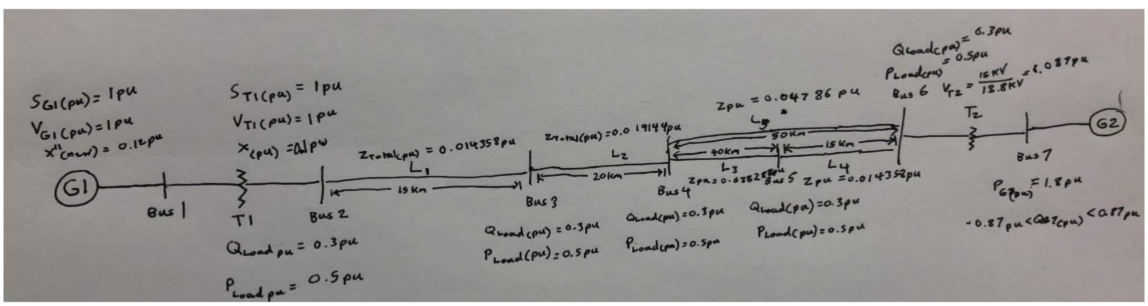


Figure 2: Per-Unit One-line Diagram

2.2 Compute All Bus Voltages

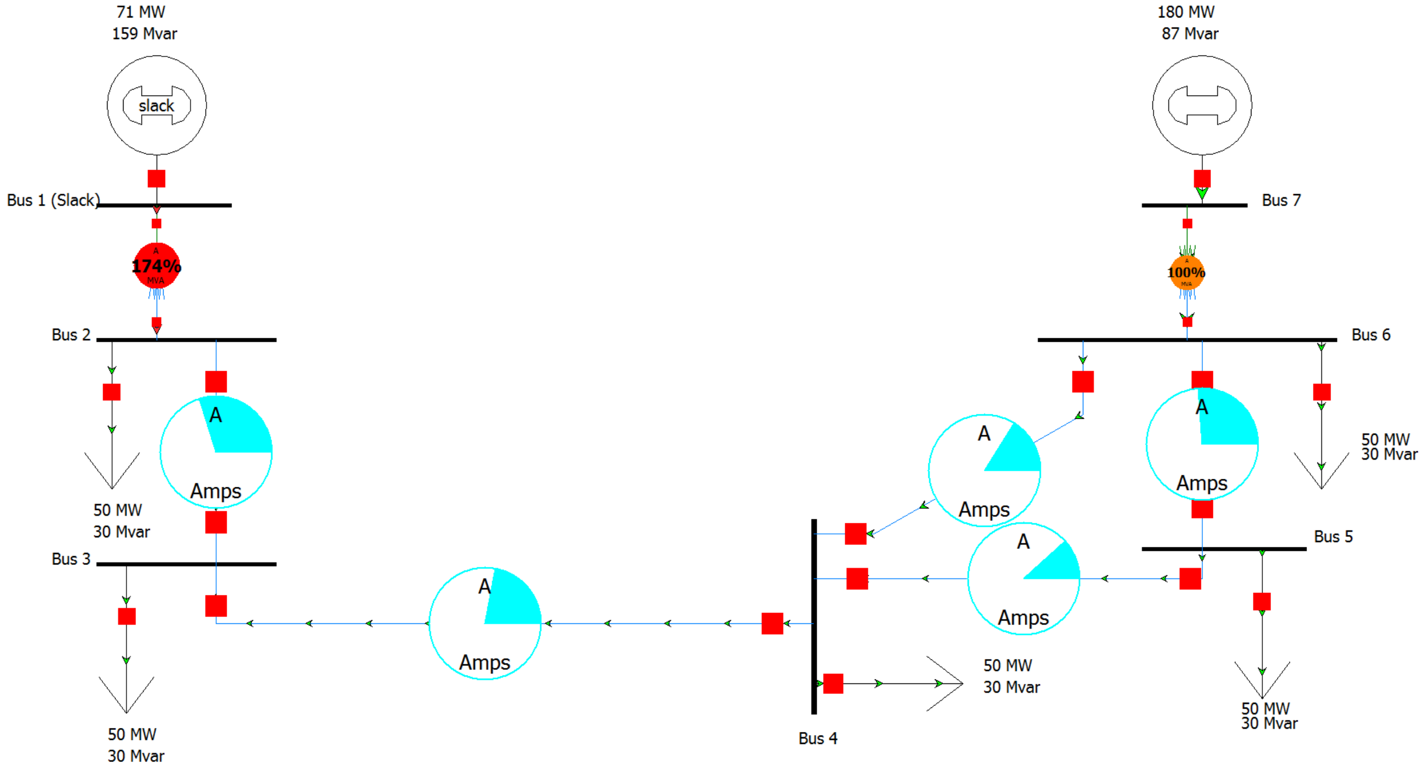


Figure 3: PowerWorld Diagram

2.2.1 Newton-Raphson Method

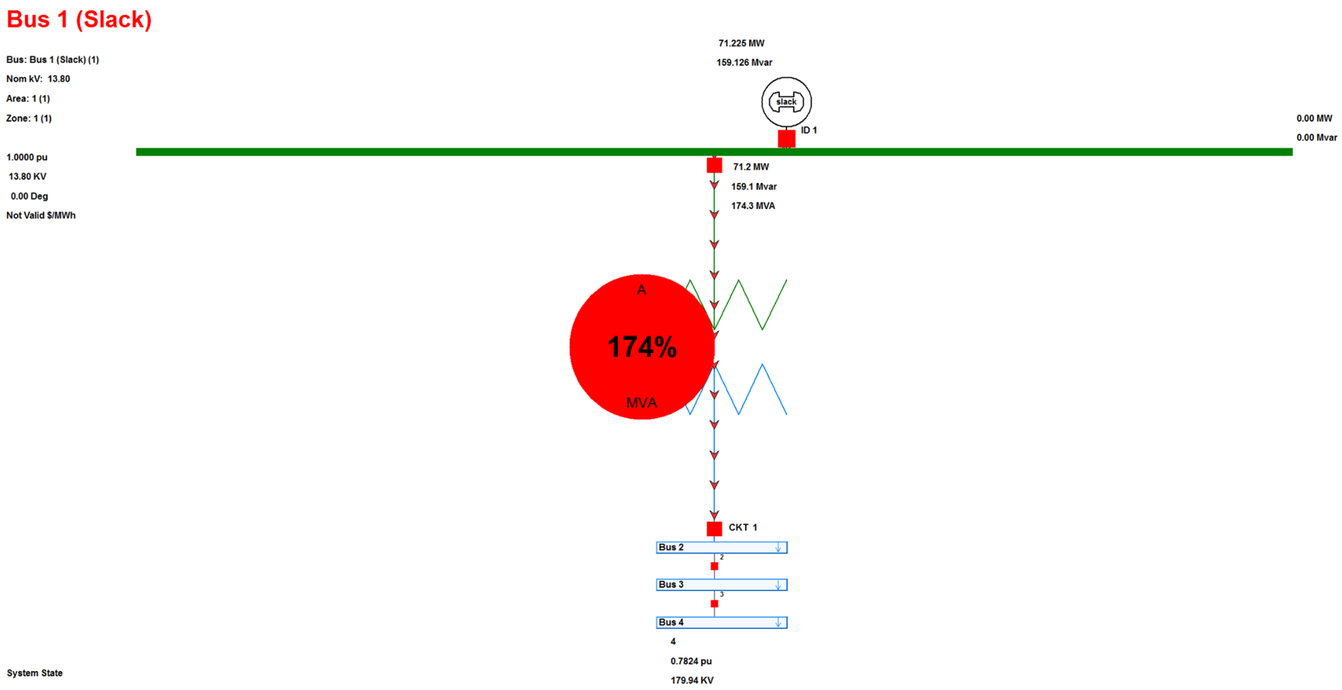


Figure 4: PowerWorld Diagram

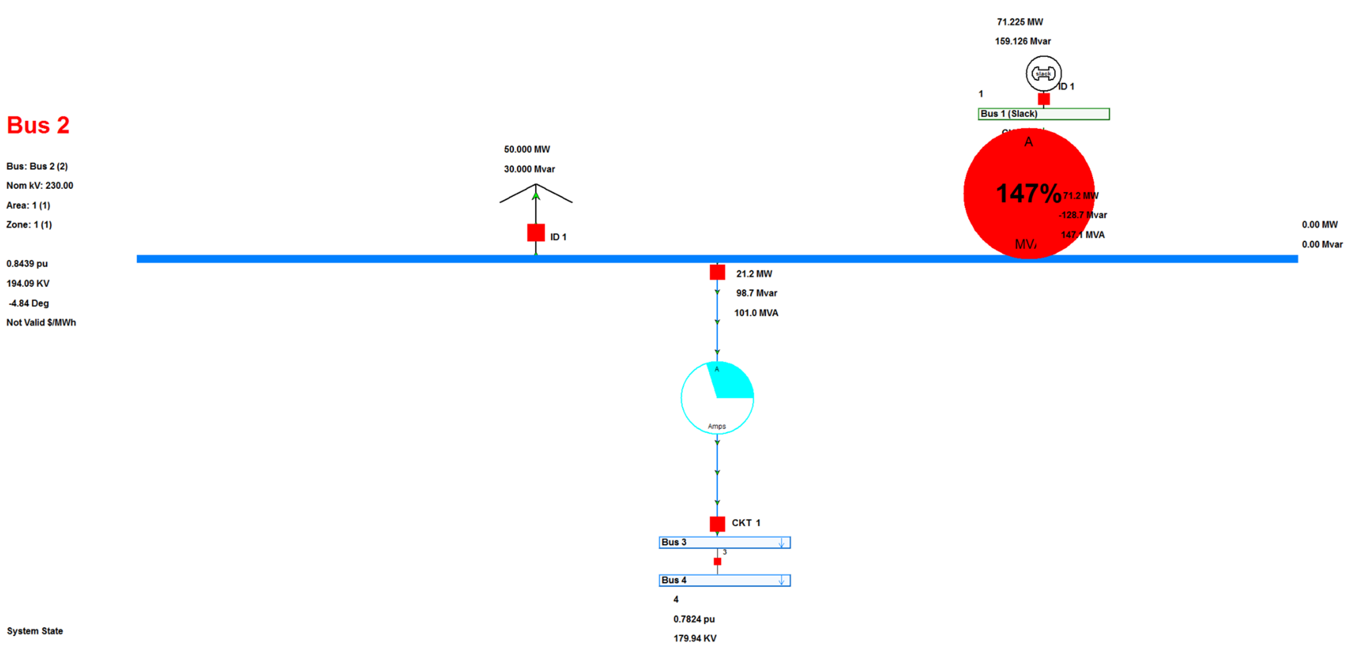


Figure 5: PowerWorld Diagram

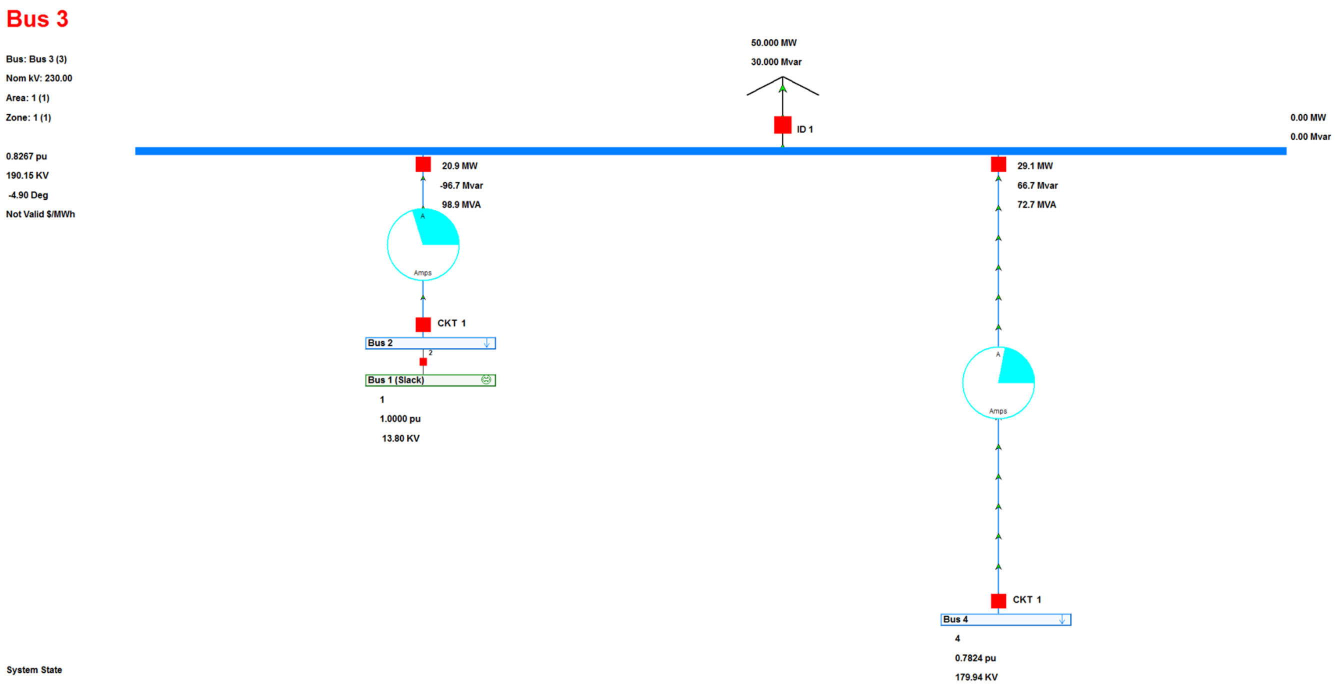


Figure 6: PowerWorld Diagram

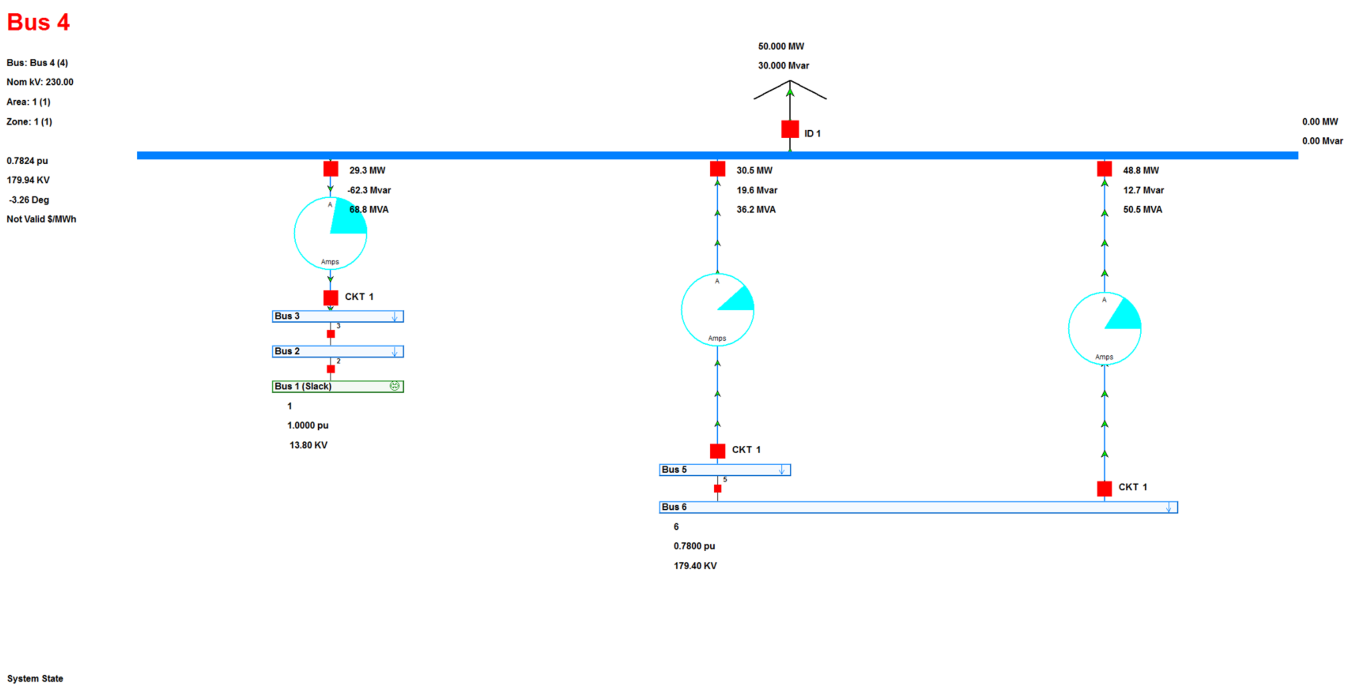


Figure 7: PowerWorld Diagram

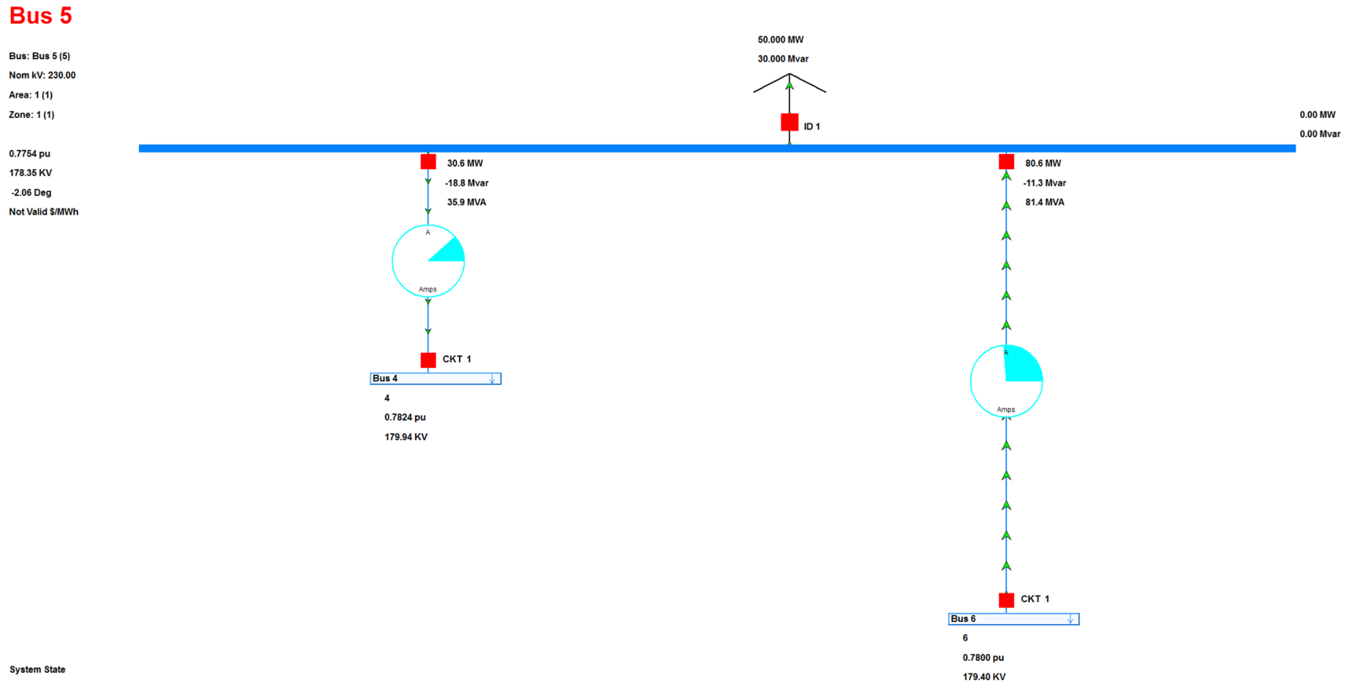


Figure 8: PowerWorld Diagram

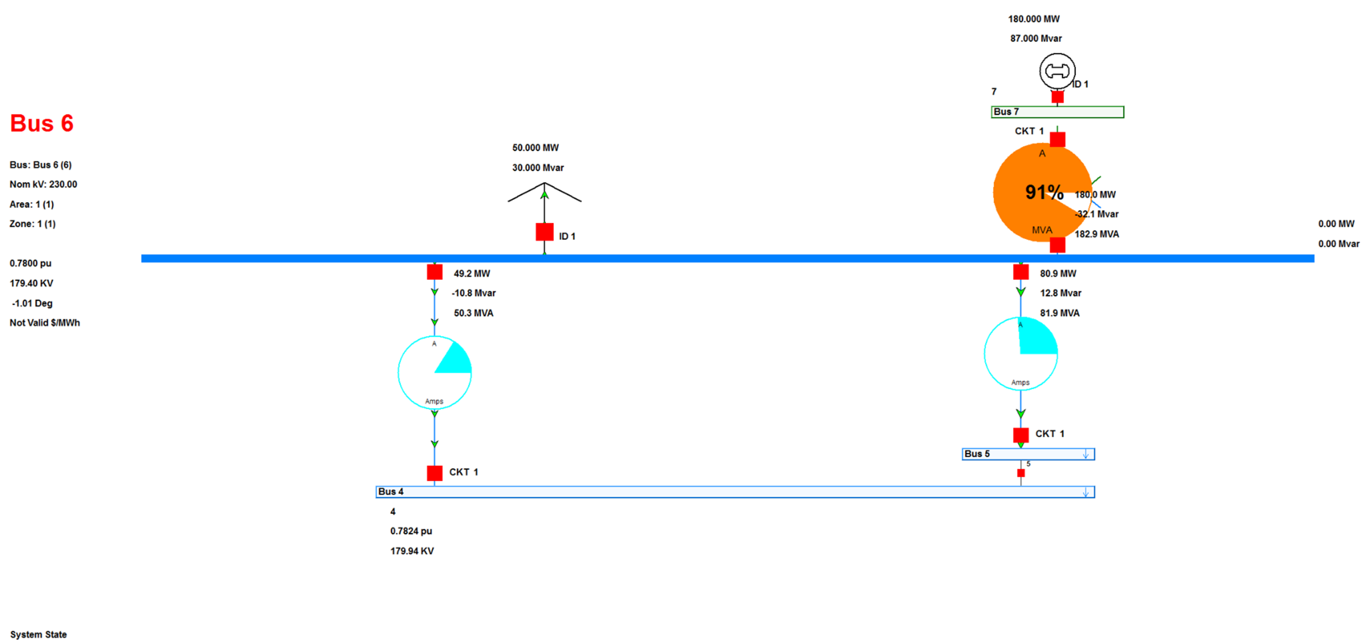


Figure 9: PowerWorld Diagram

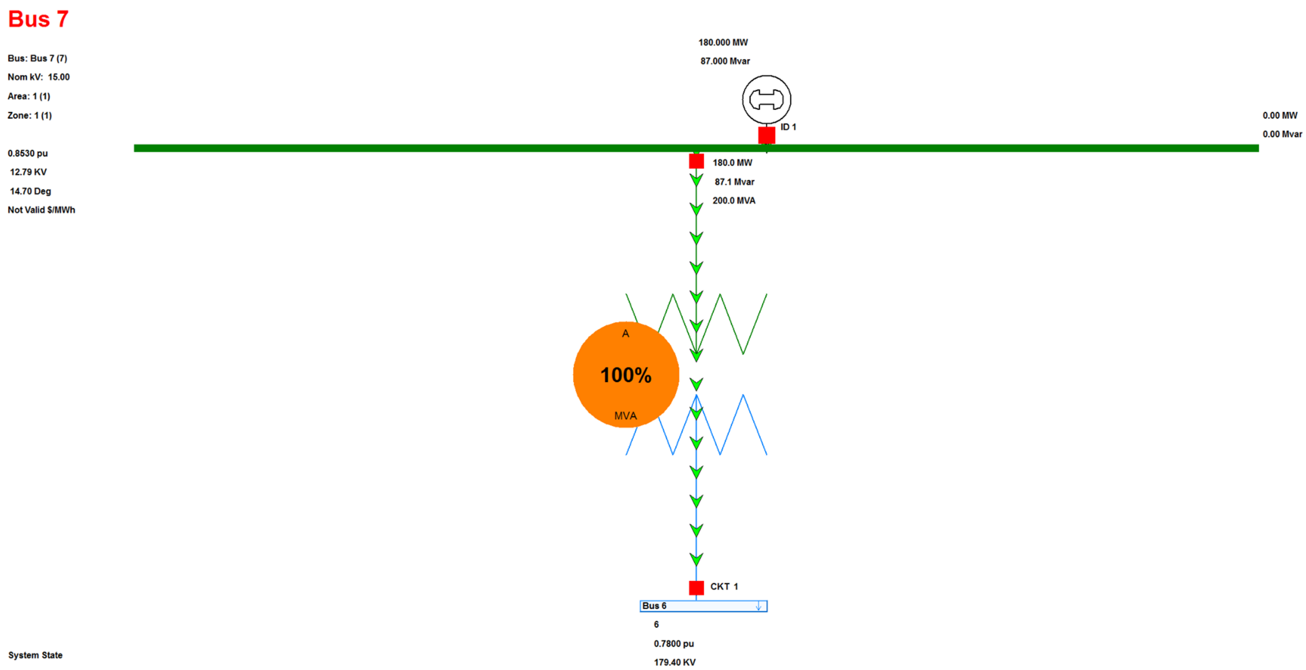
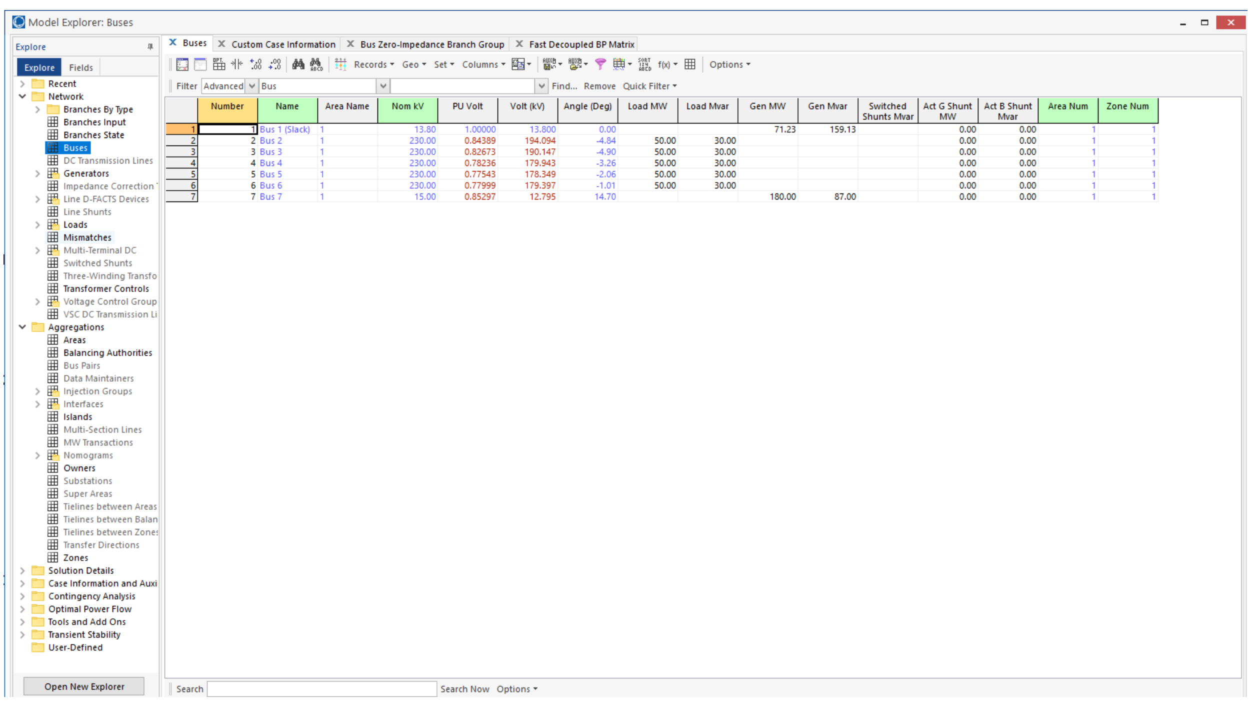


Figure 10: PowerWorld Diagram



	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	Bus 1 (Slack)	1	13.80	1.00000	13.800	0.00			71.23	159.13		0.00	0.00	1	1
2	2	Bus 2	1	230.00	0.84389	194.094	-4.84	50.00	30.00				0.00	0.00	1	1
3	3	Bus 3	1	230.00	0.82673	190.147	-4.90	50.00	30.00				0.00	0.00	1	1
4	4	Bus 4	1	230.00	0.78236	179.943	-3.26	50.00	30.00				0.00	0.00	1	1
5	5	Bus 5	1	230.00	0.77543	178.349	-2.06	50.00	30.00				0.00	0.00	1	1
6	6	Bus 6	1	230.00	0.77999	179.397	-1.01	50.00	30.00				0.00	0.00	1	1
7	7	Bus 7	1	15.00	0.85297	12.795	14.70			180.00	87.00		0.00	0.00	1	1

Figure 11: PowerWorld Diagram

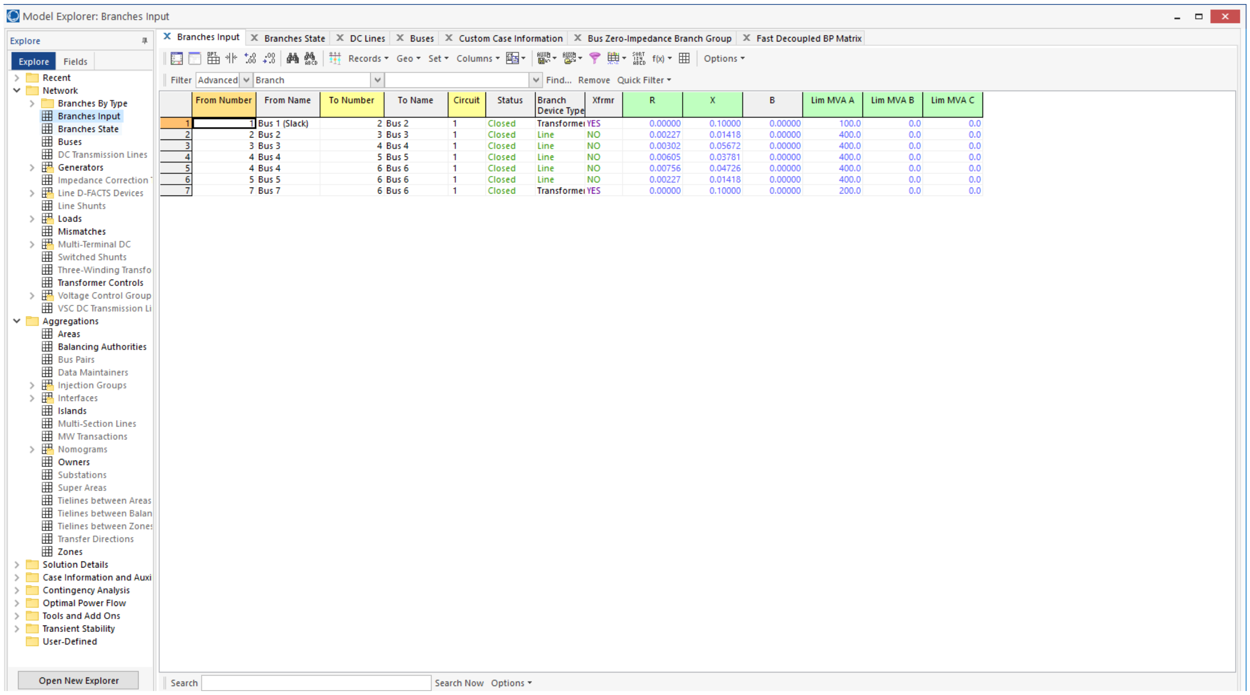


Figure 12: PowerWorld Diagram

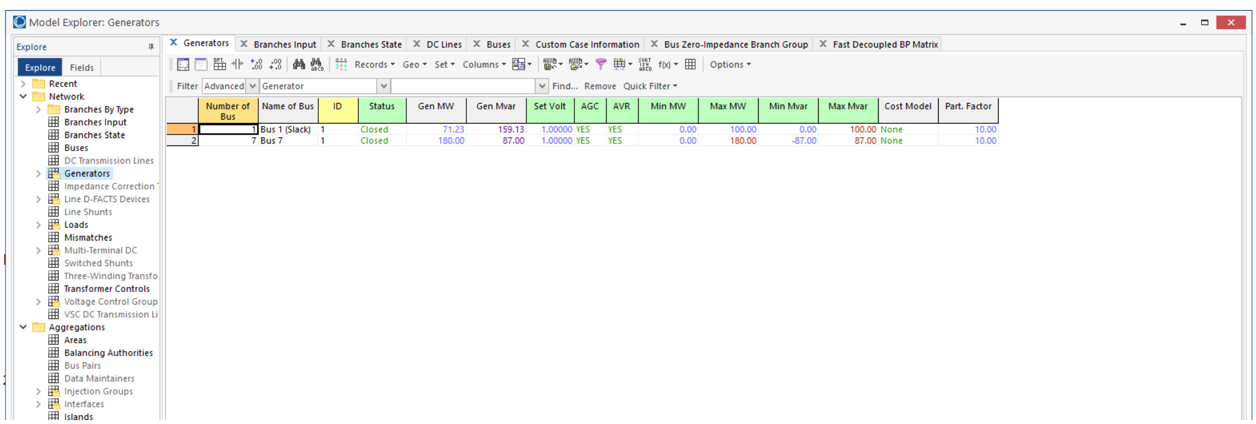


Figure 13: PowerWorld Diagram

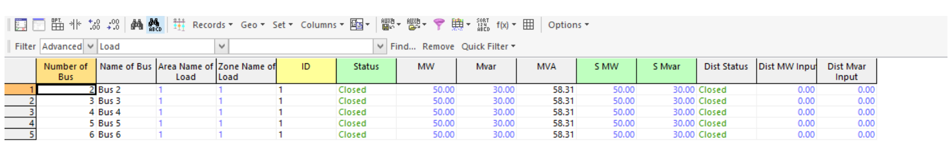


Figure 14: PowerWorld Diagram

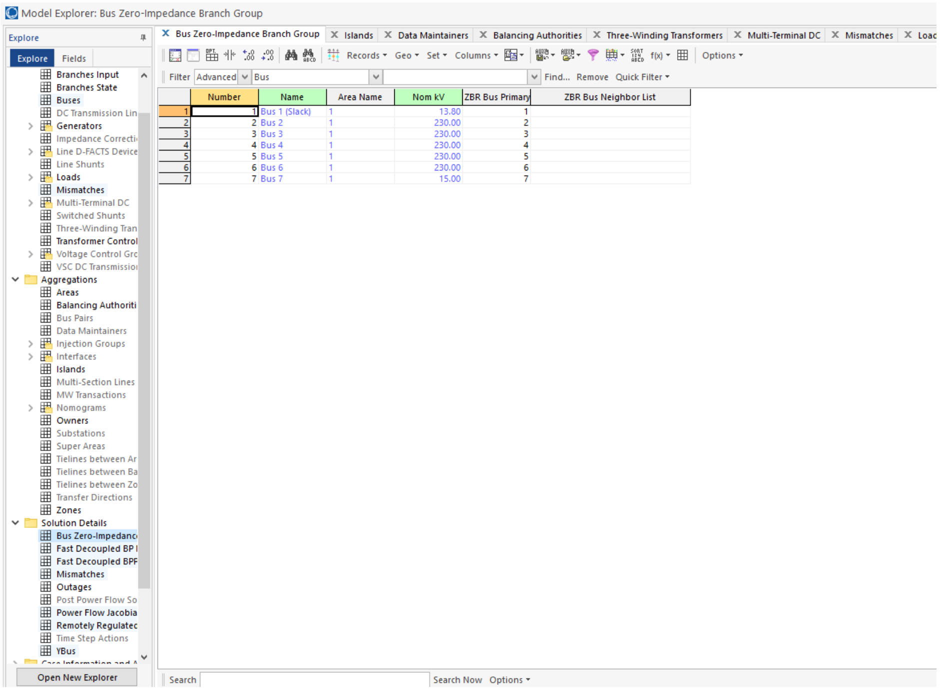


Figure 15: PowerWorld Diagram

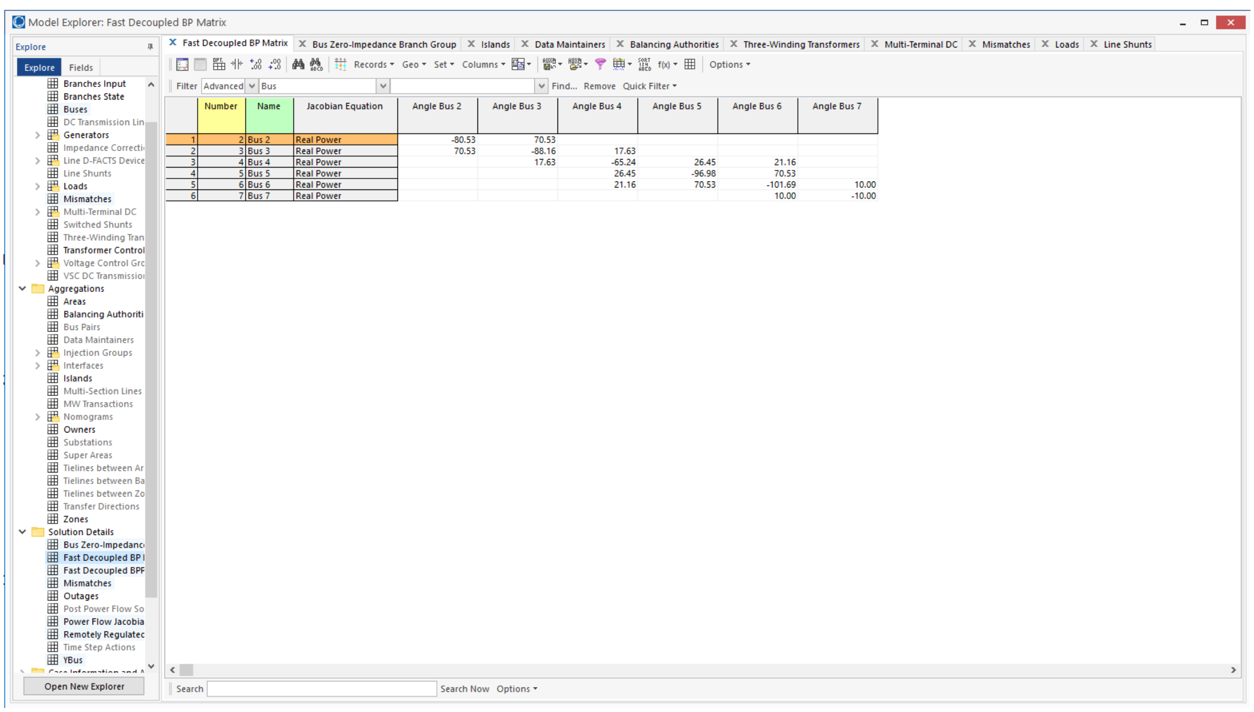
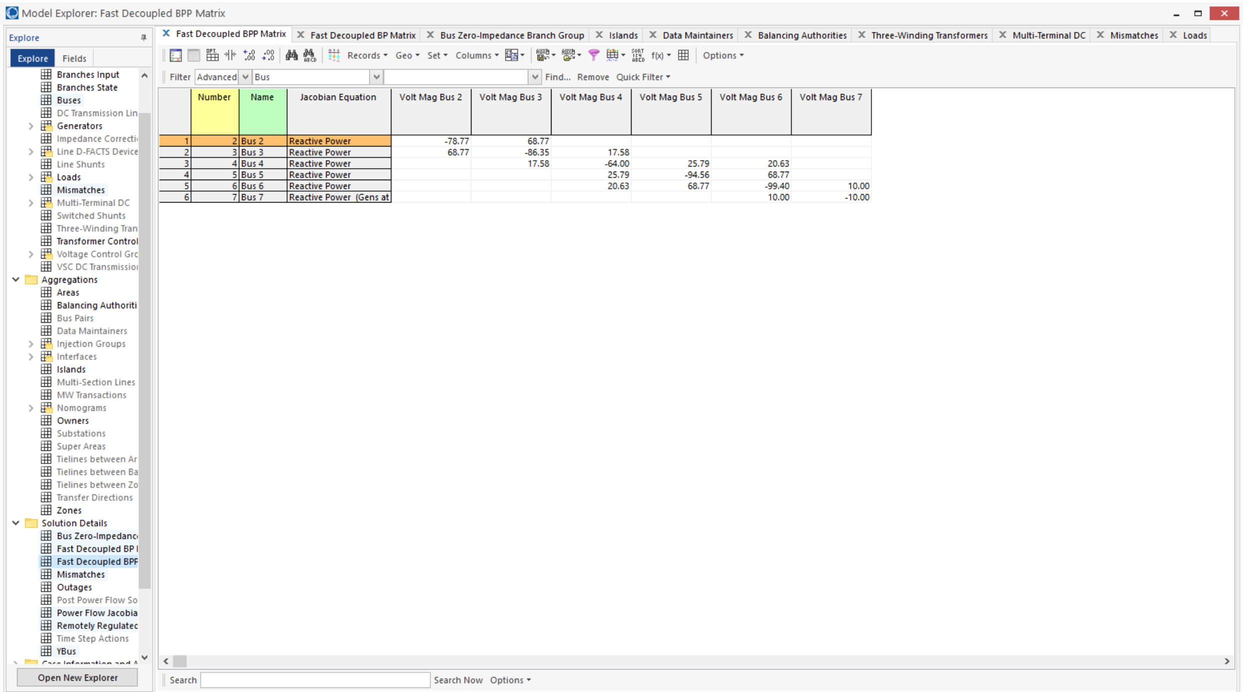
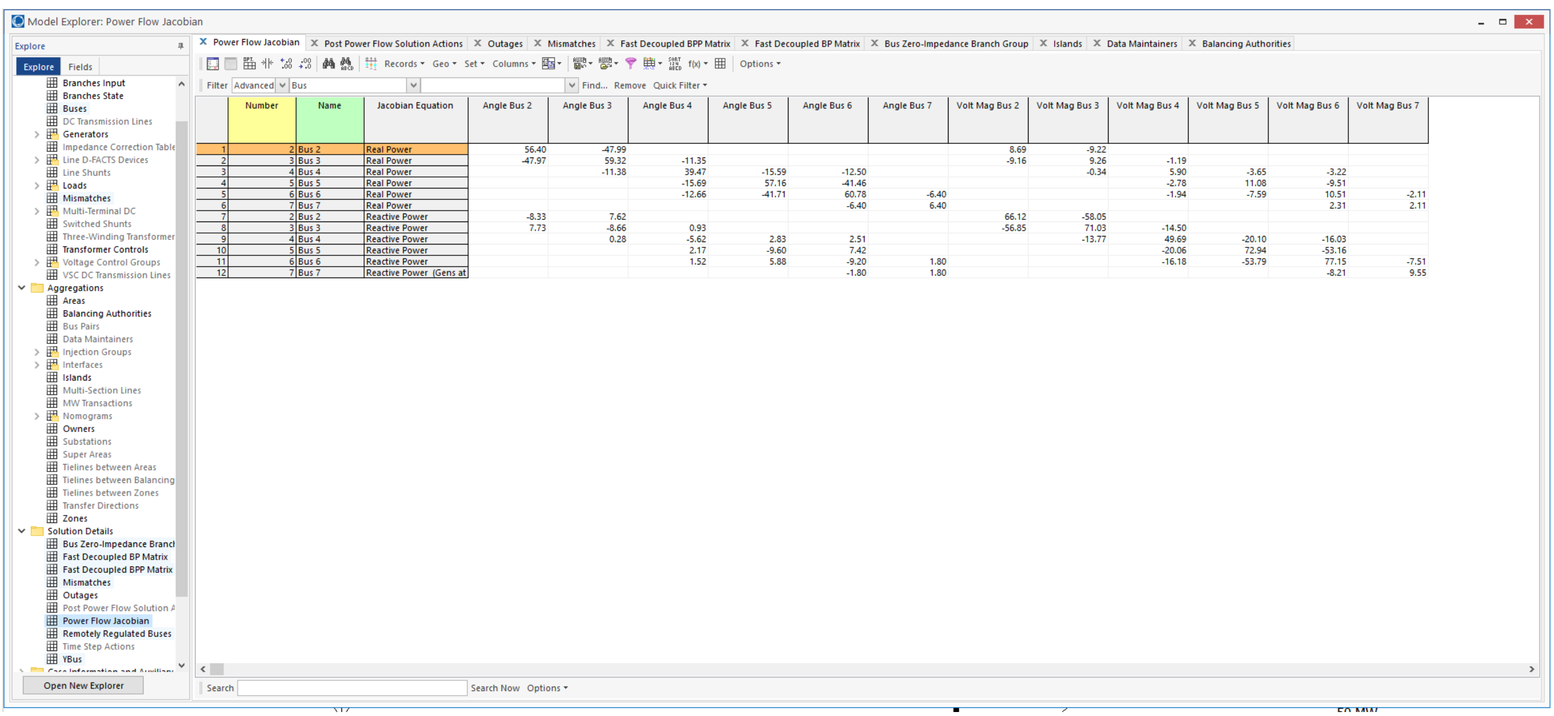


Figure 16: PowerWorld Diagram



	Number	Name	Jacobian Equation	Volt Mag Bus 2	Volt Mag Bus 3	Volt Mag Bus 4	Volt Mag Bus 5	Volt Mag Bus 6	Volt Mag Bus 7
1	2	Bus 2	Reactive Power	-78.77	68.77				
2	3	Bus 3	Reactive Power	68.77	-86.35	17.58			
3	4	Bus 4	Reactive Power		17.58	-64.00	25.79	20.63	
4	5	Bus 5	Reactive Power			25.79	-94.56	68.77	
5	6	Bus 6	Reactive Power			20.63	68.77	-99.40	10.00
6	7	Bus 7	Reactive Power (Gens at					10.00	-10.00

Figure 17: PowerWorld Diagram



	Number	Name	Jacobian Equation	Angle Bus 2	Angle Bus 3	Angle Bus 4	Angle Bus 5	Angle Bus 6	Angle Bus 7	Volt Mag Bus 2	Volt Mag Bus 3	Volt Mag Bus 4	Volt Mag Bus 5	Volt Mag Bus 6	Volt Mag Bus 7
1	2	Bus 2	Real Power	56.40	-47.99					8.69	-9.22				
2	3	Bus 3	Real Power	-47.97	59.32	-11.35				-9.16	9.26	-1.19			
3	4	Bus 4	Real Power		-11.38	39.47	-15.59	-12.50			-0.34	5.90	-3.65	-3.22	
4	5	Bus 5	Real Power			-15.69	57.16	-41.46				-2.78	11.08	-9.51	
5	6	Bus 6	Real Power			-12.66	-41.71	60.78	-6.40			-1.94	-7.59	10.51	-2.11
6	7	Bus 7	Real Power					-6.40	6.40					2.31	2.11
7	2	Bus 2	Reactive Power	-8.33	7.62					66.12	-58.05				
8	3	Bus 3	Reactive Power	7.73	-8.66	0.93				-56.85	71.03	-14.50			
9	4	Bus 4	Reactive Power		0.28	-5.62	2.83	2.51			-13.77	49.69	-20.10	-16.03	
10	5	Bus 5	Reactive Power			2.17	-9.60	7.42				-20.06	72.94	-53.16	
11	6	Bus 6	Reactive Power			1.52	5.88	-9.20	1.80			-16.18	-53.79	77.15	-7.51
12	7	Bus 7	Reactive Power (Gens at					-1.80	1.80					-8.21	9.55

Figure 18: PowerWorld Diagram

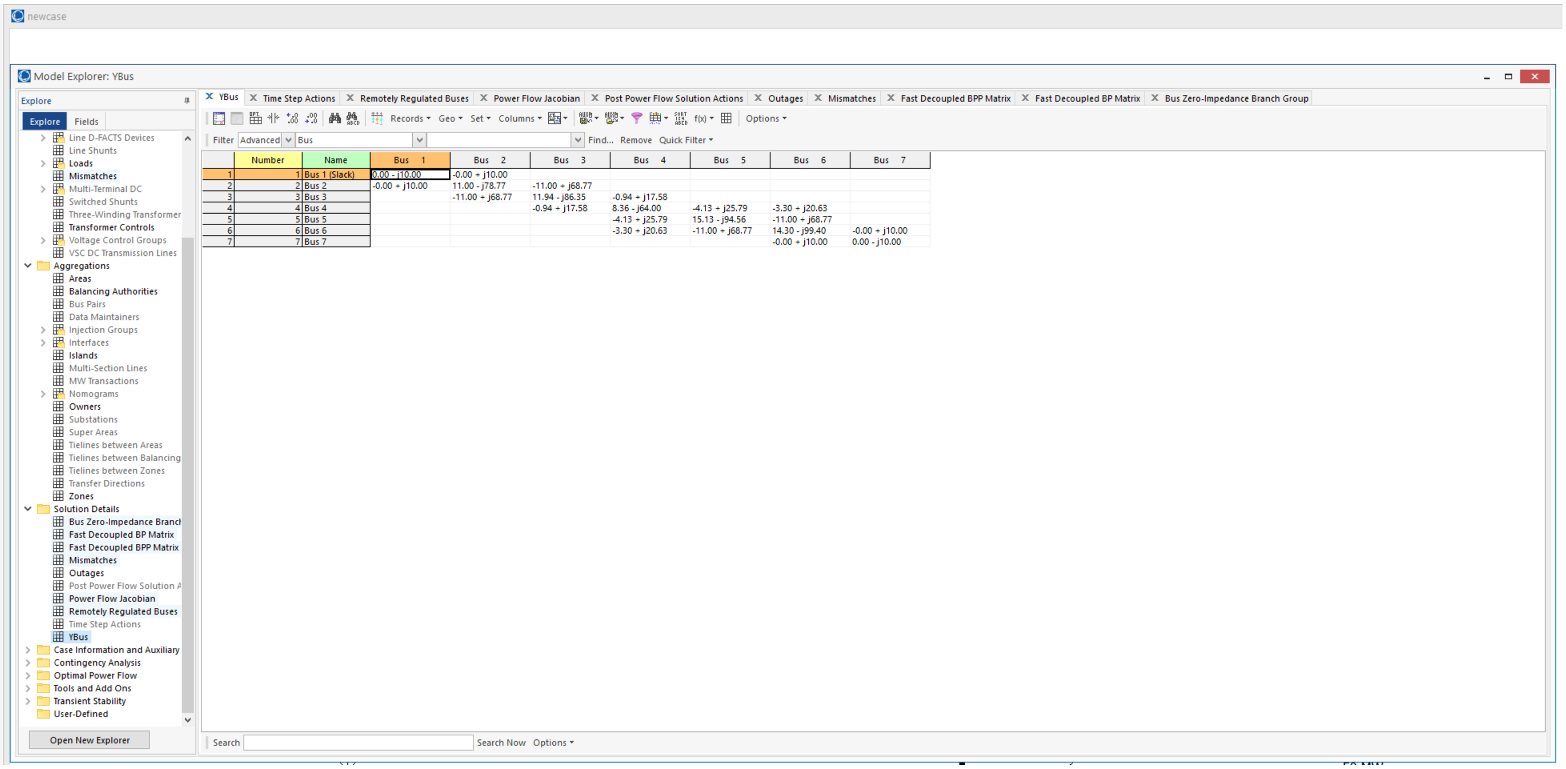


Figure 19: PowerWorld Diagram

3 Conclusions