Assignment 2

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Question 1

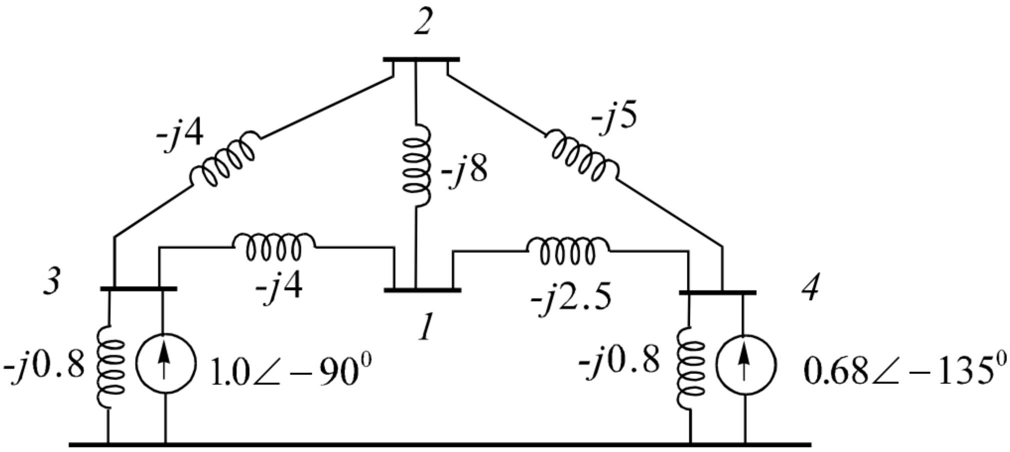

Fig. 1. Four-bus network single-line diagram.

1.1 & 1.2

nodal equations:

Bus 1: $I_1 = I_{12} + I_{13} + I_{14} = 0$

Bus 2: $I_2 = I_{21} + I_{23} + I_{24} = 0$

Bus 3: $I_3 = I_{30} + I_{31} + I_{32} = 1\angle -90° = -i$

Bus 4: $I_4 = I_{40} + I_{41} + I_{42} = 0.68\angle - 135° = \frac{(-17\times\sqrt{2})(1+i)}{50}$

Apply equation $I_{ij} = y_{ij} \times (V_i - V_j)$:

Bus 1: $I_1 = 0 = y_{12}(V_1 - V_2) + y_{13}(V_1 - V_3) + y_{14}(V_1 - V_4)$

Bus 2: $I_2 = 0 = y_{21}(V_2 - V_1) + y_{23}(V_2 - V_3) + y_{24}(V_2 - V_4)$

Bus 3: $I_3 = -i = y_{30}(V_3 - 0) + y_{31}(V_3 - V_1) + y_{32}(V_3 - V_2)$

Bus 4: $I_4 = 0.68\angle - 135° = y_{40}(V_4 - 0) + y_{41}(V_4 - V_1) + y_{42}(V_4 - V_2)$

rearrange the nodal equations:

Bus 1: $I_1 = (y_{12}+y_{13}+y_{14})\ V_1 - y_{12}\ V_2 - y_{13}\ V_3 - y_{14}\ V_4$

Bus 2: $I_2 = -y_{21}\ V_1 + (y_{21}+y_{23}+y_{24})\ V_2 - y_{23}\ V_3 - y_{24}\ V_4$

Bus 3: $I_3 = -y_{31}\ V_1 - y_{32}\ V_2 + (y_{30}+y_{31}+y_{32})\ V_3 + 0\ V_4$

Bus 4: $I_4 = -y_{41}\ V_1 - y_{42}\ V_2 + 0\ V_3 + (y_{40}+y_{41}+y_{42})\ V_4$

Define new admittances as follows:

$$Self\ admittance \begin{cases} Y_{11} = (y_{12}+y_{13}+y_{14}) = -14.5i \\ Y_{22} = (y_{21}+y_{23}+y_{24}) = -17i \\ Y_{33} = (y_{30}+y_{31}+y_{32}) = -8.8i \\ Y_{44} = (y_{40}+y_{41}+y_{42}) = -8.3i \end{cases}$$

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$$Mutual\ admittance \begin{cases} Y_{12} = Y_{21} = -y_{12} = -y_{21} = 8i \\ Y_{13} = Y_{31} = -y_{13} = -y_{31} = 4i \\ Y_{14} = Y_{41} = -y_{14} = -y_{41} = 2.5i \\ Y_{23} = Y_{32} = -y_{23} = -y_{32} = 4i \\ Y_{24} = Y_{42} = -y_{24} = -y_{42} = 5i \end{cases}$$

Apply new admittances to nodal equations:
Bus 1: $I_1 = Y_{11}V_1 + Y_{12}V_2 + Y_{13}V_3 + Y_{14}V_4 = 0$
Bus 2: $I_2 = Y_{21}V_1 + Y_{22}V_2 + Y_{23}V_3 + Y_{24}V_4 = 0$
Bus 3: $I_3 = Y_{31}V_1 + Y_{32}V_2 + Y_{33}V_3 + 0V_4 = -i$
Bus 4: $I_4 = Y_{41}V_1 + Y_{42}V_2 + 0V_3 + Y_{44}V_4 = 0.68\angle - 135°$

matrix representation of the nodal equations:

$$\begin{bmatrix} I_1 \\ I_2 \\ I_3 \\ I_4 \end{bmatrix} = \begin{bmatrix} Y_{11} & Y_{12} & Y_{13} & Y_{14} \\ Y_{21} & Y_{22} & Y_{23} & Y_{24} \\ Y_{31} & Y_{32} & Y_{33} & Y_{34} \\ Y_{41} & Y_{42} & Y_{43} & Y_{44} \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \\ V_3 \\ V_4 \end{bmatrix}$$

$$\begin{bmatrix} 0 \\ 0 \\ -i \\ 0.68\angle - 135° \end{bmatrix} = \begin{bmatrix} -14.5i & 8i & 4i & 2.5i \\ 8i & -17i & 4i & 5i \\ 4i & 4i & -8.8i & 0 \\ 2.5i & 5i & 0 & -8.3i \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \\ V_3 \\ V_4 \end{bmatrix}$$

Use Matlab to solve busbar voltages, line currents and complex power flows between buses:
Busbar voltages:

$$V = Y^{-1}I$$

$$\begin{bmatrix} V_1 \\ V_2 \\ V_3 \\ V_4 \end{bmatrix} = \begin{bmatrix} 0.9285 - 0.2978i \\ 0.9251 - 0.3009i \\ 0.9562 - 0.2721i \\ 0.8949 - 0.3289i \end{bmatrix}$$

Line currents:

$$I_{ij} = y_{ij}(V_i - V_j)$$
$$I_{ji} = y_{ji}(V_j - V_i)$$

$$\begin{bmatrix} I_{11} & I_{12} & I_{13} & I_{14} \\ I_{21} & I_{22} & I_{23} & I_{24} \\ I_{31} & I_{32} & I_{33} & I_{34} \\ I_{41} & I_{42} & I_{43} & I_{44} \end{bmatrix}$$

$$= \begin{bmatrix} 0.0000 + 0.0000i & 0.0249 - 0.0269i & -0.1026 + 0.1108i & 0.0778 - 0.0840i \\ -0.0249 + 0.0269i & 0.0000 + 0.0000i & -0.1151 + 0.1243i & 0.1400 - 0.1511i \\ 0.1026 - 0.1108i & 0.1151 - 0.1243i & 0.0000 + 0.0000i & 0.0000 + 0.0000i \\ -0.0778 + 0.0840i & -0.1400 + 0.1511i & 0.0000 + 0.0000i & 0.0000 + 0.0000i \end{bmatrix}$$

Complex power flows:

$$S_{ij} = V_i I_{ij}^* = P_{ij} + jQ_{ij}$$

$$S_{ji} = V_j I_{ji}^* = P_{ji} + jQ_{ji}$$

$$\begin{bmatrix} S_{11} & S_{12} & S_{13} & S_{14} \\ S_{21} & S_{22} & S_{23} & S_{24} \\ S_{31} & S_{32} & S_{33} & S_{34} \\ S_{41} & S_{42} & S_{43} & S_{44} \end{bmatrix}$$

$$= \begin{bmatrix} 0.0000 + 0.0000i & 0.0311 + 0.0175i & -0.1283 - 0.0723i & 0.0972 + 0.0548i \\ -0.0311 - 0.0174i & 0.0000 + 0.0000i & -0.1438 - 0.0803i & 0.1749 + 0.0977i \\ 0.1283 + 0.0780i & 0.1438 + 0.0875i & 0.0000 + 0.0000i & 0.0000 + 0.0000i \\ -0.0972 - 0.0496i & -0.1749 - 0.0892i & 0.0000 + 0.0000i & 0.0000 + 0.0000i \end{bmatrix}$$

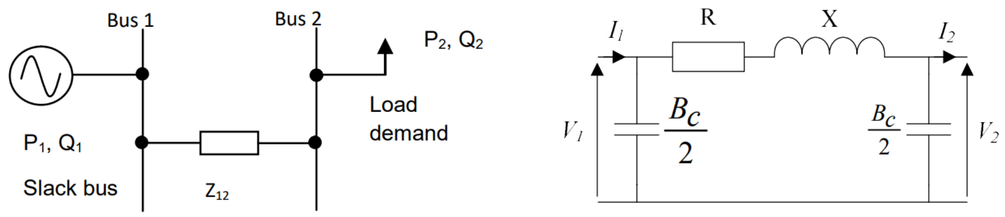
1.3

By reconstructing the admittance matrix on the basis that all the transmission lines have a total capacitive shunt admittance of 0.2 p.u and dividing the total shunt admittance into two halves connected to the terminal nodes of the line and the neutral (0) busbar, each line will have an increase of 0.1 p.u in self admittance.

There are 3 lines in bus 1 which need 0.1 p.u admittance to be added to Y_{11}, which means that there is a total 0.3 p.u admittance added to Y_{11}. Same applies to bus 2, bus 3 and bus 4.

$$\begin{bmatrix} Y_{11} & Y_{12} & Y_{13} & Y_{14} \\ Y_{21} & Y_{22} & Y_{23} & Y_{24} \\ Y_{31} & Y_{32} & Y_{33} & Y_{34} \\ Y_{41} & Y_{42} & Y_{43} & Y_{44} \end{bmatrix} = \begin{bmatrix} -14.2i & 8i & 4i & 2.5i \\ 8i & -16.7i & 4i & 5i \\ 4i & 4i & -8.6i & 0 \\ 2.5i & 5i & 0 & -8.1i \end{bmatrix}$$

Question 2



a) Single-line diagram

b) Pi equivalent circuit model

Fig. 2. Question 2: Two-bus network.

Table. 1. Question 2: Input data

Bus	V(pu)	Δ(rad)	P(pu)	Q(pu)
1	1	0	-	-
2	-	-	-0.8	-0.2
Branch	R(pu)	X(pu)	$B_c/2$(pu)	
1-2	0.1	0.4	0.1	

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Construct admittance matrix Y:

$$Y=\begin{bmatrix}Y_{11} & Y_{12}\\ Y_{21} & Y_{22}\end{bmatrix}=\begin{bmatrix}y_{10}+y_{12} & -y_{12}\\ -y_{21} & y_{20}+y_{21}\end{bmatrix}=\begin{bmatrix}0.1i+\frac{1}{0.1+0.4i} & -\frac{1}{0.1+0.4i}\\ -\frac{1}{0.1+0.4i} & 0.1i+\frac{1}{0.1+0.4i}\end{bmatrix}$$

$$=\begin{bmatrix}2.33\angle-75.37° & 2.43\angle104.04°\\ 2.43\angle104.04° & 2.33\angle-75.37°\end{bmatrix}$$

Assuming $V_2=1\angle0°$

We know $V_1=1\angle0°$ because bus 1 is slack bus.

Input (active and reactive power injections or drains):

$$f(x)^{(0)}=\begin{bmatrix}f_1(x)^{(0)}=|V_2||V_1||Y_{21}|\cos(\delta_2-\delta_1-\theta_{21})+|V_2|^2|Y_{22}|\cos(-\theta_{22})\\ f_2(x)^{(0)}=|V_2||V_1||Y_{21}|\sin(\delta_2-\delta_1-\theta_{21})+|V_2|^2|Y_{22}|\sin(-\theta_{22})\end{bmatrix}$$

$$=\begin{bmatrix}|1||1||2.43|\cos(0°-0°-104.04°)+|1|^2|2.33|\cos(75.37°)\\ |1||1||2.43|\sin(0°-0°-104.04°)+|1|^2|2.33|\sin(75.37°)\end{bmatrix}$$

$$=\begin{bmatrix}-0.00\\ -0.10\end{bmatrix}$$

The Jacobian matrix of partial derivatives:

$$J(x)=\begin{bmatrix}\frac{\partial f_1(x)}{\partial\delta_2} & \frac{\partial f_1(x)}{\partial V_2}\\ \frac{\partial f_2(x)}{\partial\delta_2} & \frac{\partial f_2(x)}{\partial V_2}\end{bmatrix}$$

$$=\begin{bmatrix}-|V_2||V_1||Y_{21}|\sin(\delta_2-\delta_1-\theta_{21}) & |V_1||Y_{21}|\cos(\delta_2-\delta_1-\theta_{21})+2|V_2||Y_{22}|\cos(-\theta_{22})\\ |V_2||V_1||Y_{21}|\cos(\delta_2-\delta_1-\theta_{21}) & |V_1||Y_{21}|\sin(\delta_2-\delta_1-\theta_{21})+2|V_2||Y_{22}|\sin(-\theta_{22})\end{bmatrix}$$

$$=\begin{bmatrix}-|1||1||2.43|\sin(0°-0°-104.04°) & |1||2.43|\cos(0°-0°-104.04°)+2|1||2.33|\cos(75.37°)\\ |1||1||2.43|\cos(0°-0°-104.04°) & |1||2.43|\sin(0°-0°-104.04°)+2|1||2.33|\sin(75.37°)\end{bmatrix}$$

$$=\begin{bmatrix}2.36 & 0.59\\ -0.59 & 2.15\end{bmatrix}$$

Because $\begin{bmatrix}a & b\\ c & d\end{bmatrix}^{-1}=\frac{1}{ad-bc}\begin{bmatrix}d & -b\\ -c & a\end{bmatrix}$

so $J(x)^{-1}=\frac{1}{2.36\times2.25-0.59\times(-0.59)}\begin{bmatrix}2.15 & -0.59\\ 0.59 & 2.36\end{bmatrix}=\begin{bmatrix}0.38 & -0.10\\ 0.10 & 0.42\end{bmatrix}$

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First iteration:

$$\begin{bmatrix} \Delta\delta_2{}^{(0)} \\ \Delta V_2{}^{(0)} \end{bmatrix} = \begin{bmatrix} \frac{\partial f_1(x)}{\partial \delta_2} & \frac{\partial f_1(x)}{\partial V_2} \\ \frac{\partial f_2(x)}{\partial \delta_2} & \frac{\partial f_2(x)}{\partial V_2} \end{bmatrix}^{-1} \begin{bmatrix} \Delta P = P_2 - f_1(x)^{(0)} \\ \Delta Q = Q_2 - f_2(x)^{(0)} \end{bmatrix}$$

$$= \begin{bmatrix} 0.38 & -0.10 \\ 0.10 & 0.42 \end{bmatrix} \begin{bmatrix} -0.8 - (-0.00) \\ -0.2 - (-0.10) \end{bmatrix} = \begin{bmatrix} -0.29 \\ -0.12 \end{bmatrix}$$

$$\begin{bmatrix} \delta_2{}^{(1)} \\ V_2{}^{(1)} \end{bmatrix} = \begin{bmatrix} \delta_2{}^{(0)} + \Delta\delta_2{}^{(0)} \\ V_2{}^{(0)} + \Delta V_2{}^{(0)} \end{bmatrix} = \begin{bmatrix} 0 + (-0.29rad) \\ 1 + (-0.12) \end{bmatrix} = \begin{bmatrix} -16.62° \\ 0.88 \end{bmatrix}$$

Question 3:

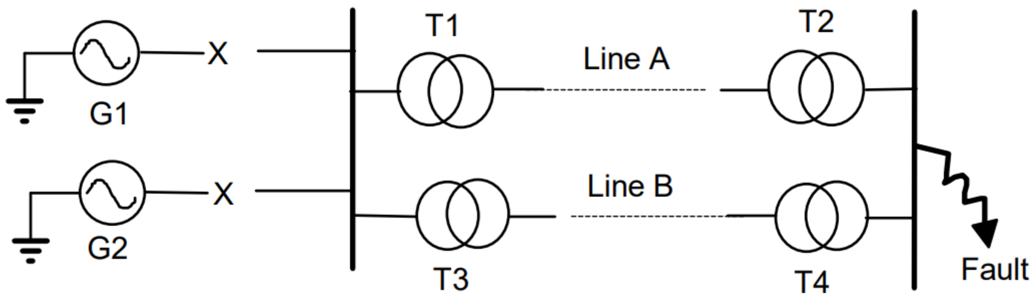

Fig. 3. Question 3: Single-line Diagram.

Choose 9 MVA base and convert all p.u reactances as Table. 2.

Table. 2. Question 3 input data

Component	Own base(MVA)	Reactance(pu)	New base(MVA)	New Reactance(pu)
G1	21	0.28	9	0.120
G2	9	0.3	9	0.300
T1	18	0.07	9	0.035
T2	18	0.07	9	0.035
T3	9	0.08	9	0.080
T4	9	0.066	9	0.066
Line A		10Ω	9	$10 \times \frac{9}{66^2} = 0.021$
Line B		20Ω	9	$20 \times \frac{9}{33^2} = 0.165$

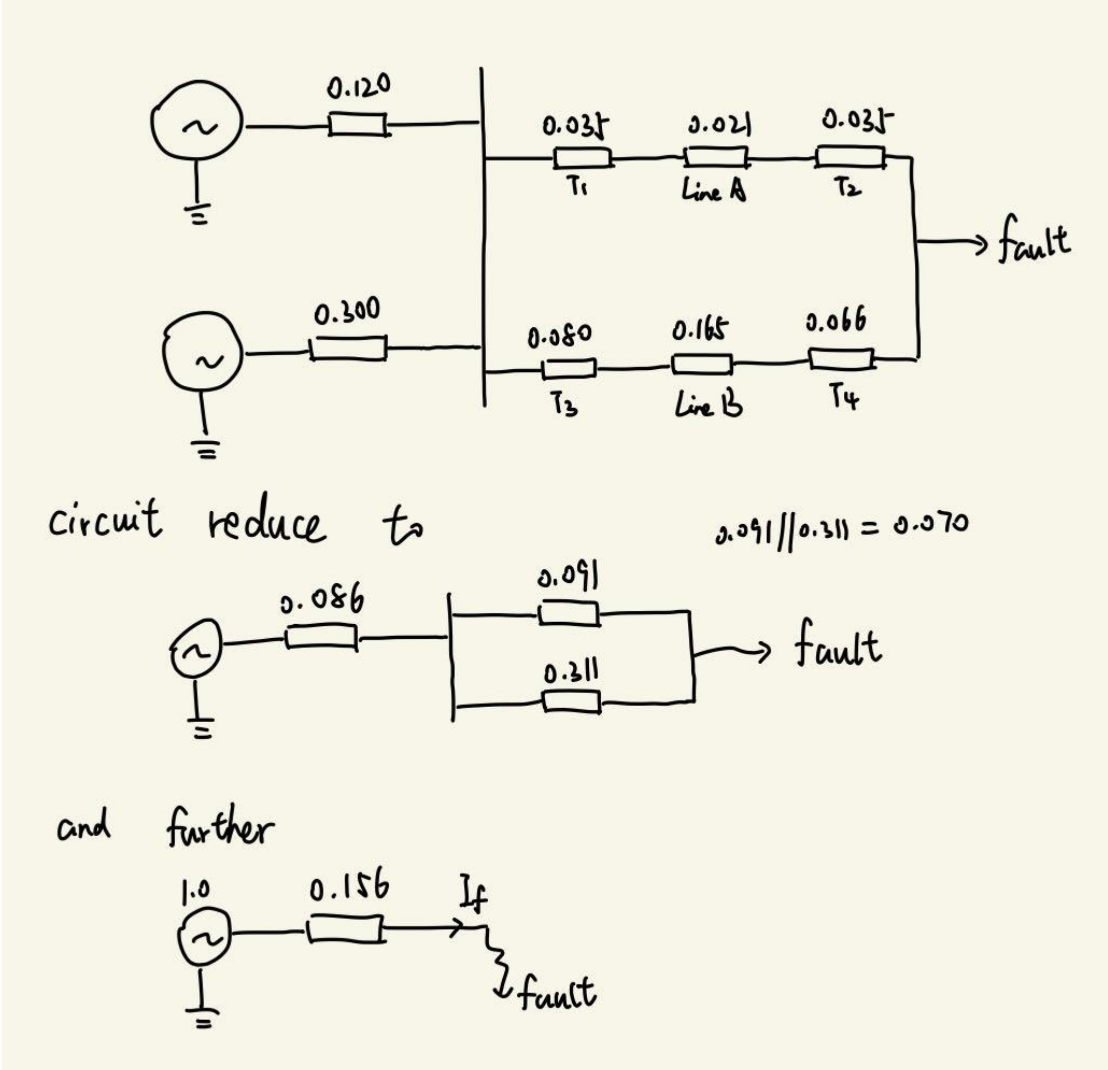

Fig. 4. Converting to Single voltage source feeding fault diagram.

$$X_f = 0.156\ pu$$

$$I_{f\_pu} = \frac{1.0}{0.156} = 6.410\ pu$$

$$9\text{ MVA @ }17.3\text{kV} \Rightarrow I_{base1} = \frac{9\ MVA}{\sqrt{3} \times 17.3kV} = 300.356A$$

$$9\text{ MVA @ }66\text{kV} \Rightarrow I_{base2} = \frac{9\ MVA}{\sqrt{3} \times 66kV} = 78.730A$$

$$9\text{ MVA @ }33\text{kV} \Rightarrow I_{base3} = \frac{9\ MVA}{\sqrt{3} \times 33kV} = 157.459A$$

$$9\text{ MVA @ }11\text{kV} \Rightarrow I_{base4} = \frac{9\ MVA}{\sqrt{3} \times 11kV} = 472.377A$$

Evaluate currents in G1, G2, Line A, Line B and I_f:

$$I_{G1} = \frac{0.086}{0.120} \times I_{f\_pu} \times I_{base1} = \frac{0.086}{0.120} \times 6.410\ pu \times 300.356A = 1379.785A$$

$$I_{G2} = \frac{0.086}{0.300} \times I_{f\_pu} \times I_{base1} = \frac{0.086}{0.300} \times 6.410\ pu \times 300.356A = 551.914A$$

$$I_{lineA} = \frac{0.070}{0.091} \times I_{f\_pu} \times I_{base2} = \frac{0.070}{0.091} \times 6.410\ pu \times 78.730A = 388.199A$$

$$I_{lineB} = \frac{0.070}{0.311} \times I_{f\_pu} \times I_{base3} = \frac{0.070}{0.311} \times 6.410\ pu \times 157.459A = 227.176A$$

$$I_f = I_{f\_pu} \times I_{base4} = 6.410\ pu \times 472.377A = 3027.937A$$

Question 4:

4.1

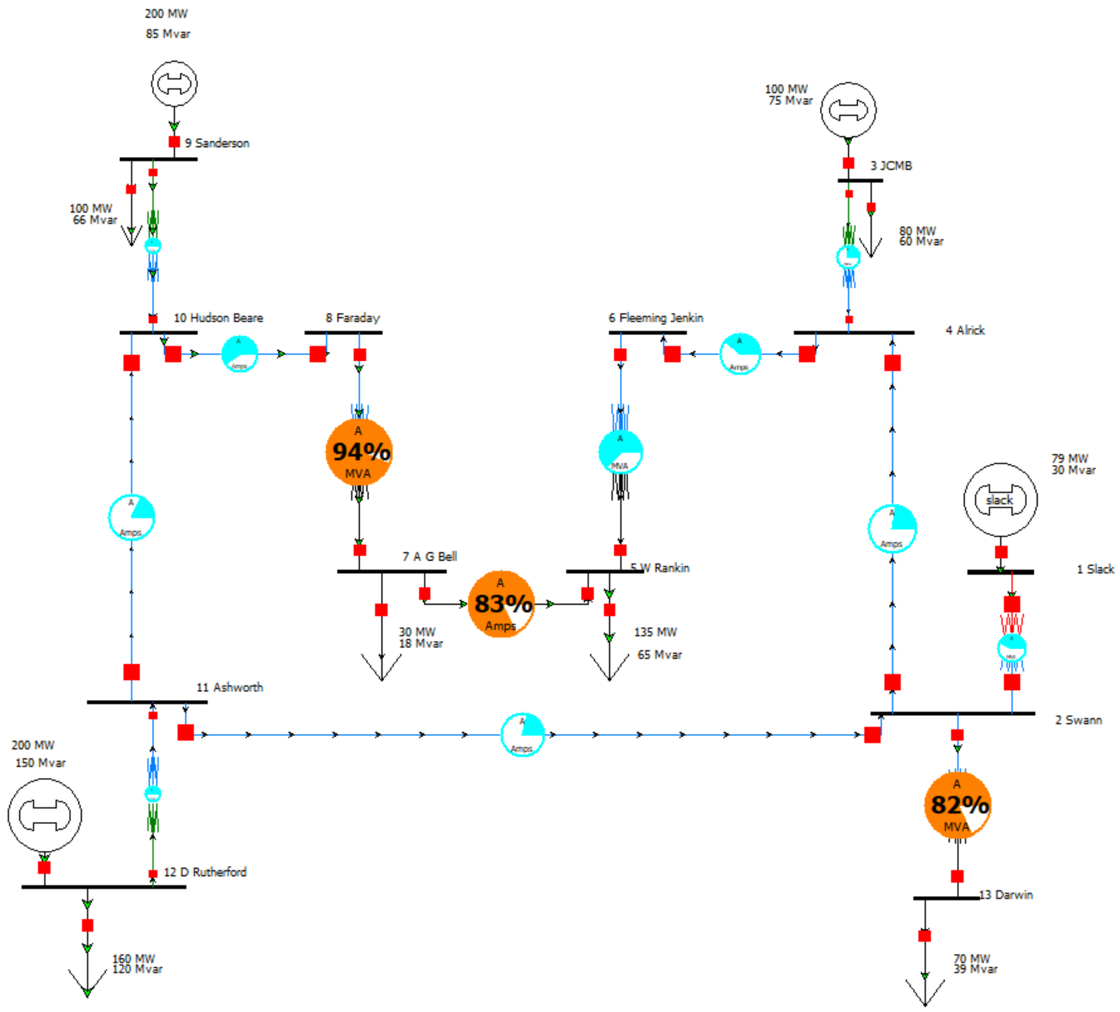

Fig. 5. The 13-bus network single-line diagram.

Table. 3. Input Data (transformer and line impedances)

From bus	To bus	Type	Rating (MVA)	R (pu)	X (pu)	B(pu)
1	2	T	200	0.00350	0.03500	0.00000
3	4	T	100	0.00385	0.03850	0.00000
5	6	T	120	0.00167	0.04167	0.00000
7	8	T	120	0.00167	0.04167	0.00000
9	10	T	200	0.00350	0.03500	0.00000

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11	12	T	100	0.00385	0.03850	0.00000
2	13	T	100	0.00500	0.05000	0.00000
2	4	L	200	0.01664	0.08978	0.18640
4	6	L	200	0.00665	0.03519	0.07460
5	7	L	100	0.00830	0.04555	0.00810
8	10	L	200	0.00665	0.03519	0.07460
10	11	L	200	0.00980	0.05279	0.11190
2	11	L	200	0.01664	0.08978	0.18640

Note: All transformer resistances and reactances are converted in per-unit to a base of 100 MVA using formula: $X_{pu}(new) = X_{pu}(old)(\frac{MVA(new)}{MVA(old)})$.

4.2

	Num ▲	Name	Area Name	Nom kV	PU Volt	Volt (kV)	Angle (Deg)	Load MW	Load Mvar	Gen MW	Gen Mvar
1	1	1 Slack	1	345.00	1.00000	345.000	0.000			78.963	30.269
2	2	2 Swann	1	230.00	0.98700	227.010	-1.543				
3	3	3 JCMB	1	13.80	0.97087	13.398	-3.263	80.000	60.000	100.000	75.000
4	4	4 Alrick	1	230.00	0.96415	221.755	-3.698				
5	5	5 W Rankin	1	115.00	0.92435	106.301	-6.566	135.000	65.383		
6	6	6 Fleeming Jenkin	1	230.00	0.94443	217.220	-4.909				
7	7	7 A G Bell	1	115.00	0.94323	108.471	-4.519	29.995	18.036		
8	8	8 Faraday	1	230.00	0.96582	222.138	-1.858				
9	9	9 Sanderson	1	13.80	0.99999	13.800	2.126	99.960	66.393	200.000	84.625
10	10	10 Hudson Beare	1	230.00	0.99070	227.861	0.137				
11	11	11 Ashworth	1	230.00	1.00620	231.426	0.123				
12	12	12 D Rutherford	1	13.80	1.01894	14.061	0.919	160.000	120.000	200.000	150.000
13	13	13 Darwin	1	115.00	0.96262	110.701	-3.536	70.000	38.730		

Fig. 6. Buses

	From Num ▲	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 Slack	2	2 Swann	1	Closed	Transforme	YES	79.0	30.3	84.6	200.0	42.3	0.25	2.50
2	2	2 Swann	4	4 Alrick	1	Closed	Line	NO	43.2	8.8	44.1	200.0	24.7	0.37	-15.73
3	2	2 Swann	11	11 Ashworth	1	Closed	Line	NO	-34.8	-23.3	41.9	200.0	20.9	0.24	-17.21
4	2	2 Swann	13	13 Darwin	1	Closed	Transforme	YES	70.3	42.2	82.0	100.0	82.0	0.35	3.45
5	3	3 JCMB	4	4 Alrick	1	Closed	Transforme	YES	20.0	15.0	25.0	100.0	25.0	0.03	0.26
6	4	4 Alrick	6	6 Fleeming Jen	1	Closed	Line	NO	62.8	39.3	74.0	200.0	38.1	0.41	-4.61
7	5	5 W Rankin	6	6 Fleeming Jen	1	Closed	Transforme	YES	-62.2	-41.2	74.6	120.0	63.5	0.11	2.72
8	5	5 W Rankin	7	7 A G Bell	1	Closed	Line	NO	-72.7	-24.2	76.6	100.0	78.0	0.57	2.42
9	7	7 A G Bell	8	8 Faraday	1	Closed	Transforme	YES	-103.3	-44.6	112.5	120.0	96.0	0.24	5.93
10	8	8 Faraday	10	10 Hudson Bea	1	Closed	Line	NO	-103.5	-50.6	115.2	200.0	57.6	0.92	-2.26
11	9	9 Sanderson	10	10 Hudson Bea	1	Closed	Transforme	YES	100.0	18.2	101.7	200.0	50.8	0.36	3.62
12	10	10 Hudson Bea	11	11 Ashworth	1	Closed	Line	NO	-4.8	-33.7	34.0	200.0	17.0	0.08	-10.72
13	11	11 Ashworth	12	12 D Rutherfor	1	Closed	Transforme	YES	-39.9	-29.0	49.3	100.0	50.0	0.09	0.93

Fig. 7. Branches State

Table. 4. The Bus Records & Load and PQ Generated

Num	Nom kV	pu Volt	Volt (kV)	Angle (Deg)	Load MW	Load Mvar	Gen MW	Gen Mvar
1	345.00	1.00000	345.000	0.000			78.963	30.269
2	230.00	0.98700	227.010	-1.543				
3	13.80	0.97087	13.398	-3.263	80.000	60.000	100.000	75.000
4	230.00	0.96415	221.755	-3.698				
5	115.00	0.92435	106.301	-6.566	135.000	65.383		
6	230.00	0.94443	217.220	-4.909				

7	115.00	0.94323	108.471	-4.519	29.995	18.036		
8	230.00	0.96582	222.138	-1.858				
9	13.80	0.99999	13.800	2.126	99.960	66.393	200.000	84.625
10	230.00	0.99070	227.861	0.137				
11	230.00	1.00620	231.426	0.123				
12	13.80	1.01894	14.061	0.919	160.000	120.000	200.000	150.000
13	115.00	0.96262	110.701	-3.536	70.000	38.730		
Total					574.955	368.542	578.963	339.894

Table. 5. Line Records & Active Power (MW) losses and Mvar stored

From bus	To bus	Type	MW From	Mvar From	MVA From	Lim MVA	% of thermal Limit (Max)	MW Loss	Mvar Loss/Stored
1	2	T	79.0	30.3	84.6	200.0	42.3	0.25	2.50
2	4	L	43.2	8.8	44.1	200.0	24.7	0.37	-15.73
2	11	L	-34.8	-23.3	41.9	200.0	20.9	0.24	-17.21
2	13	T	70.3	42.2	82.0	100.0	82.0	0.35	3.45
3	4	T	20.0	15.0	25.0	100.0	25.0	0.03	0.26
4	6	L	62.8	39.3	74.0	200.0	38.1	0.41	-4.61
5	6	T	-62.2	-41.2	74.6	120.0	63.5	0.11	2.72
5	7	L	-72.7	-24.2	76.6	100.0	78.0	0.57	2.42
7	8	T	-103.3	-44.6	112.5	120.0	96.0	0.24	5.93
8	10	L	-103.5	-50.6	115.2	200.0	57.6	0.92	-2.26
9	10	T	100.0	18.2	101.7	200.0	50.8	0.36	3.62
10	11	L	-4.8	-33.7	34.0	200.0	17.0	0.08	-10.72
11	12	T	-39.9	-29.0	49.3	100.0	50.0	0.09	0.93
Total								4.02	-27.70

$$P_{Gen} = 578.963MW$$
$$Q_{Gen} = 339.894Mvar$$
$$P_{Load} = 574.955MW$$
$$Q_{Load} = 368.542Mvar$$
$$P_{losses} = 4.02MW$$
$$Q_{losses\&Stored} = -27.70Mvar$$
$$P_{Gen} \approx P_{Load} + P_{losses}$$
$$Q_{Gen} \approx Q_{Load} + Q_{losses\&stored}$$

Conclusion: Ignore round-off errors in the system, the system is balanced.

4.3

Table. 6. Fault Level Study with generator at Busbar 9 on

Bus Number	I_f Mag (pu)	I_f Angle (deg)	I_f Mag (A)	Fault level (MVA)
1	26.782	-86.22	4481.890	2678.2
2	20.457	-82.52	5135.100	2045.7
3	12.375	-82.95	51773.200	1237.5
4	13.810	-81.65	3466.500	1381.0
5	10.332	-80.02	5186.960	1033.2
6	11.317	-80.98	2840.740	1131.7
7	10.308	-80.09	5175.250	1030.8
8	11.548	-78.70	2898.690	1154.8
9	13.084	-77.00	54739.700	1308.4
10	14.500	-77.69	3639.840	1450.0
11	16.339	-78.19	4101.520	1633.9
12	14.394	-77.45	60218.100	1439.4
13	10.154	-83.27	5097.600	1015.4
Note:$S_{fault} = S_{fault\_pu} \times S_{base} = V_{pu} \times I_{f\_pu} \times S_{base} = 1 \times I_{f\_pu} \times 100MVA$				

Table. 7. Fault Level Study with generator at Busbar 9 off

Bus Number	I_f Mag (pu)	I_f Angle (deg)	I_f Mag (A)	Fault level (MVA)
1	27.144	-84.66	4542.480	2714.1
2	18.881	-83.48	4739.540	1888.1
3	10.471	-88.15	43807.400	1047.1
4	11.688	-86.11	2934.020	1168.8
5	8.123	-87.25	4078.310	812.3
6	9.196	-87.02	2308.430	919.6
7	7.506	-89.43	3768.550	750.6
8	7.755	-88.82	1946.570	775.5
9	6.439	-88.99	26938.600	643.9
10	8.878	-85.85	2228.640	887.8
11	12.443	-83.48	3123.390	1244.3
12	11.654	-82.94	48757.100	1165.4
13	9.283	-85.90	4660.530	928.3
Note:$S_{fault} = S_{fault\_pu} \times S_{base} = V_{pu} \times I_{f\_pu} \times S_{base} = 1 \times I_{f\_pu} \times 100MVA$				

- Table. 6. shows that when short circuit fault happens close to a generator such as bus 3, bus 9 and bus 12, not including slack bus, the actual fault current would be extremely high.
- Table. 6. & Table. 7. shows that when disconnect generator from bus 9, the actual

fault current and fault level at bus 9 are about half of the magnitude when the generator at bus 9 is on.

4.4

1).

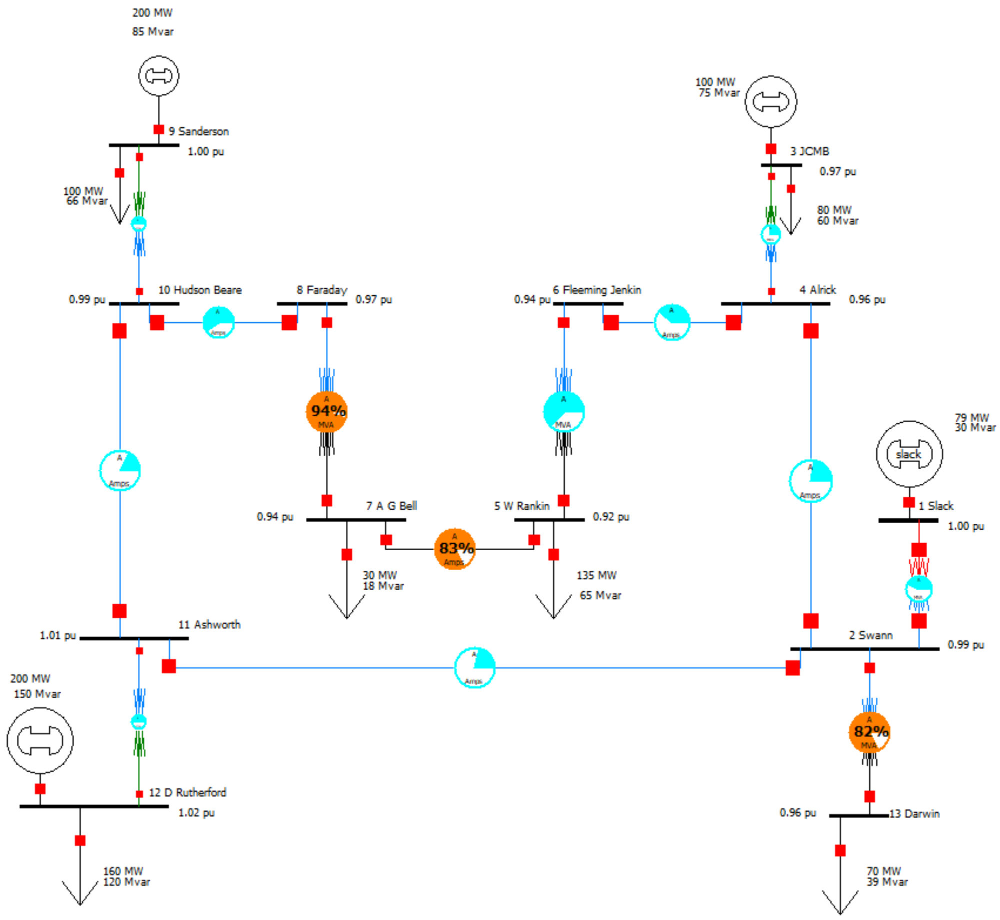

Fig. 8. The 13-bus network single-line diagram.

From transformer between bus 7 and bus 8, line between bus 5 and bus 7, transformer between bus 2 and bus 13, we can notice that the loadings in the lines and transformers are higher when the lines or transformers are further away from a generator bus such as bus 1, bus 3, bus 9, bus 12.

The distribution of busbar voltage in power system is affected by the distance between the power source, such as bus 1, bus 3, bus 9, bus 12, and the load centers such as bus 5, bus 7 and bus 13. As power is transmitted over long distances, the voltage level at the busbar decreases due to the resistance and impedance of the transmission lines.

2).

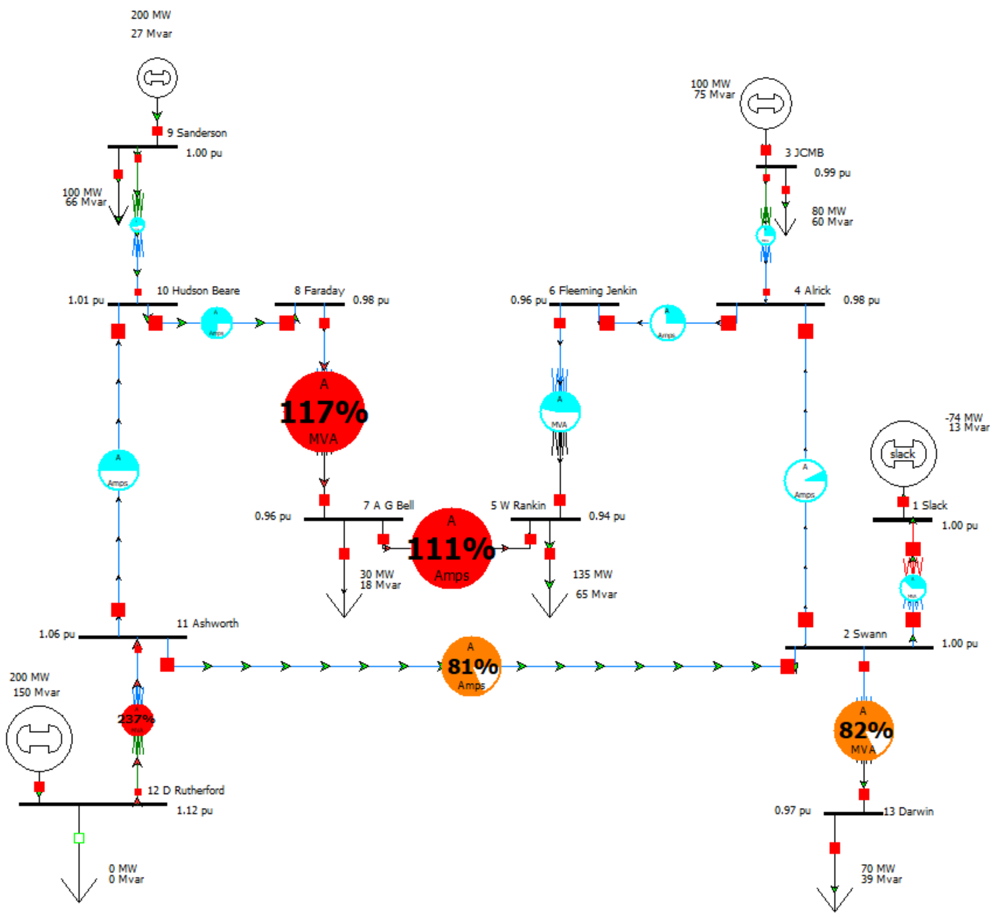

Fig. 9. The 13-bus network single-line diagram.

Analyse the effects of load disconnection:

When a large load is disconnected suddenly in a power system, the remaining equipment such as transformers and transmission lines may become overloaded.

Load disconnection can cause transformers to become overloaded because transformers are designed to operate within specific load limits. When a large load is disconnected suddenly, the load demand on the transformer decreases rapidly. If the power output of the transformer is not reduced quickly enough to match the reduced load demand, the transformer can become overloaded.

Load disconnection can cause transmission lines to become overloaded because when a large load is disconnected, the load demand on the transmission lines decreases. And the remaining load demand may be concentrated on a smaller number of transmission lines.

Observations:

- The transformer between bus 11 and bus 12 is heavily overloaded because it is closest to bus 12 which is the busbar that has a sudden change of load.
- The transmission line between bus 5 and bus 7 is overloaded because it is the furthest from all generator buses. The remaining load demand due to the

disconnection of load at bus 12 is concentrated here.

- The P & Q generated by slack bus is also reduced since there are more power flow in the system than demand comparing to connecting load at bus 12.

3).

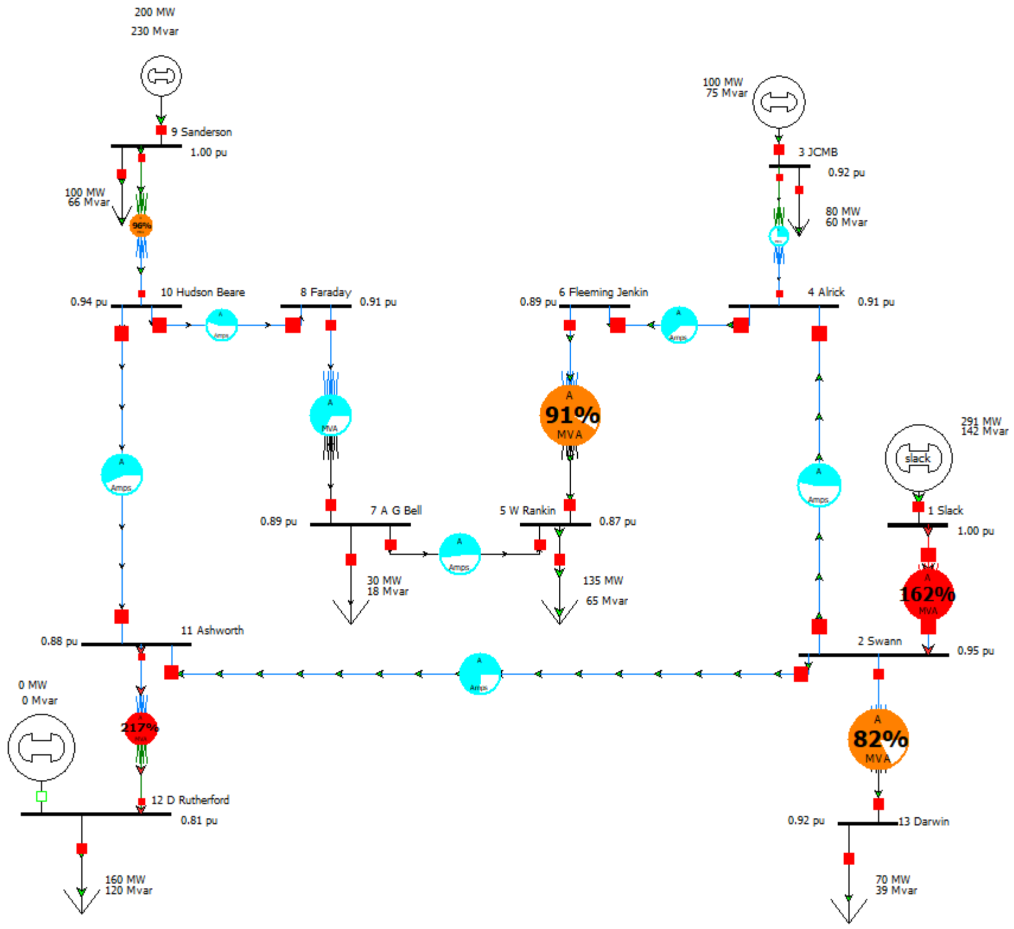

Fig. 10. The 13-bus network single-line diagram.

Analyse the effects of generator disconnection:

When a generator is disconnected from the grid, the remaining generators may have to increase their output to compensate for the loss of generation. This additional load may cause the transformers in the system to become overloaded.

The direction of power flow in the system can also be changed when a generator is disconnected. Depending on the topology of the system, this could result in power flowing in a different direction through the transformers.

Observations:

- The P & Q generated by other generators at bus 1, bus 3, bus 9 have increased in order to compensate for the loss of generation. Especially for the slack bus bus 1, it is now generating a lot more P & Q compared to which the generator at bus 12 is on.
- The direction of power flow at transmission lines bus 10-bus 11, bus 2-bus 11 and transformer between bus 11-bus 12 has reversed. At transformer between bus 11-

bus 12,, the reversed power flow has exceeded its rated capacity, which causes it to be heavily overloaded.

4.5

Table. 8. Data in bus 13

Pset (MW)	Qset (Mvar)	Pget (MW)	Qget (Mvar)	Voltage Mag (pu)	Voltage Angel (Deg)
70	38.700	70.000	38.700	0.963	-3.536
140	77.400	140.000	77.400	0.917	-7.235
210	116.100	210.000	116.100	0.860	-11.482
280	154.800	280.000	154.800	0.782	-16.807
350	193.500	344.710	190.575	0.645	-25.229
420	232.200	350.211	193.617	0.513	-32.585
490	270.900	329.229	182.017	0.428	-36.990
560	309.600	304.913	168.574	0.370	-39.908

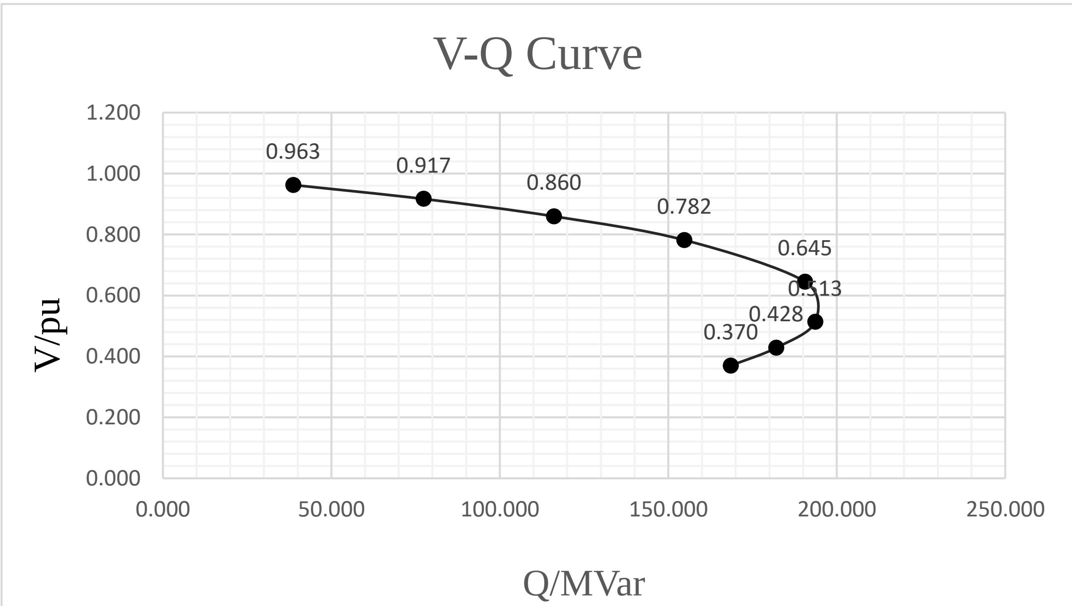

Fig. 11. V-Q Curve in Bus 13

$$Q_r \approx \frac{V_r V_s}{X} - \frac{V_r^2}{X}$$

The PQ Bus Bus 13 does not have an automatic voltage regulation function for its generator, meaning it cannot adjust Q to maintain its voltage. Instead, it follows a quadratic function of V_r as the equation above. When Q load increases, the voltage decreases. There is a critical point at the V-Q curve. After reaching the critical point, if the load demand continues to increase, the Qget will start to drop along with the voltage. It is impossible to reach 560MW and 310MVar as it exceeds the limit by a large margin.

4.6

Tabel. 9. Data in Bus 9

	Pset (MW)	Qset (Mvar)	Pget (MW)	Qget (Mvar)	Voltage Mag (pu)	Voltage Angel (Deg)
var limits : ±9900 Mvar	99.960	66.393	99.960	66.393	1.000	2.125
	149.960	99.393	149.960	99.393	1.000	-2.813
	199.960	132.393	199.960	132.393	1.000	-7.828
	249.960	165.393	249.960	165.393	1.000	-12.965
	299.960	198.393	299.960	198.393	1.000	-18.307
	349.960	231.393	349.960	231.393	1.000	-23.927
	399.960	264.393	399.960	264.393	1.000	-29.945
	449.960	297.393	449.960	297.393	1.000	-36.561
	499.960	330.393	499.960	330.393	1.000	-44.152
	549.960	363.393	549.960	363.393	1.000	-53.683
	599.960	396.393	599.960	396.393	1.000	-72.771
var limits : ±120 Mvar	99.960	66.393	99.960	66.393	1.060	1.306
	149.960	99.393	149.960	99.393	0.997	-2.774
	199.960	132.393	199.960	132.393	0.916	-7.521
	249.960	165.393	249.960	165.393	0.801	-13.728
	299.960	198.393	288.295	190.678	0.612	-22.818
	349.960	231.393	295.705	195.520	0.520	-26.968
	399.960	264.393	297.123	196.413	0.463	-29.451
	449.960	297.393	296.752	196.133	0.422	-31.144
	499.960	330.393	295.528	195.297	0.391	-32.394
	549.960	363.393	293.872	194.180	0.365	-33.357
	599.960	396.393	292.006	192.928	0.344	-34.117

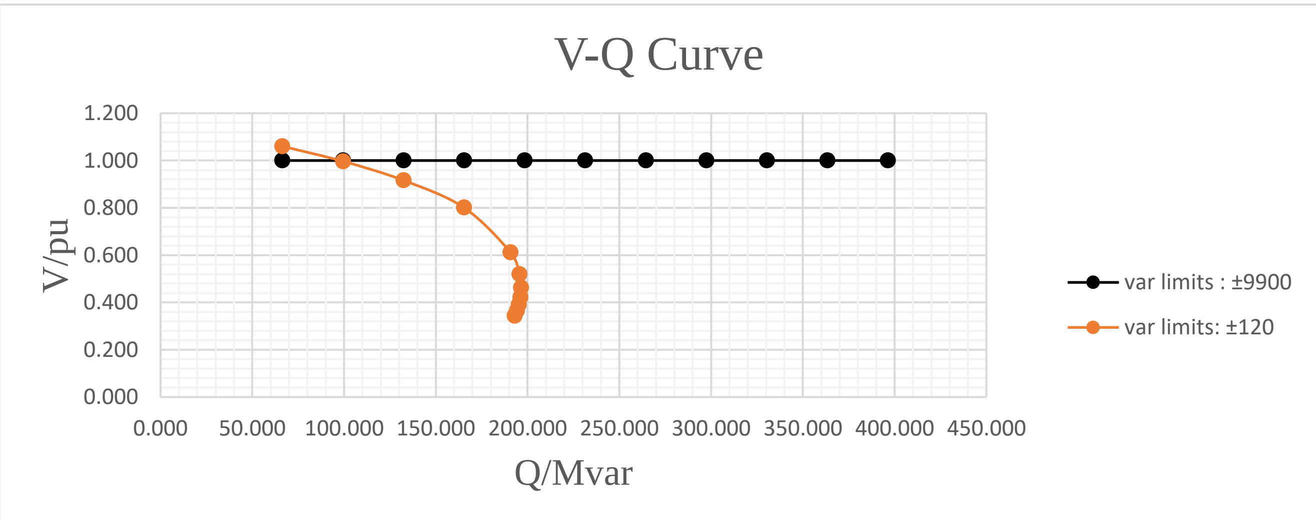

Fig. 12. V-Q Curve in Bus 9

Black curve in Fig. 12. represents that the var limits for generator 9 is ±9900Mvar. And since Bus 9 is a PV bus, and Generator 9 is equipped with an automatic voltage regulation function, it has a robust capability to adjust its Q to maintain a voltage of 1pu. From the curve we can see that it is a flat line, there is no critical point. As the load on Bus 9 increases, the voltage remains constant at 1pu, and the demand can always be met, even when the load reaches as high as 600MW and 400MVar.

Orange curve in Fig. 12. represents that the var limits for generator 9 is ±120Mvar. In this situation, its ability to maintain the Busbar voltage becomes limited. Initially, the voltage regulation ability remains relatively stable as long as the var demand does not exceed the 120MVar limit. However, when the var surpasses the limit, Bus 9 will function similarly to a PQ bus. From the curve we can see that Qget is a quadratic function of V_r again, and there is a critical point. Beyond this critical point, the Qget will decrease, which means the Bus will be unable to reach 600MW and 400MVar.

Assignment 2

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Appendix:

Matlab code for Question 1:

```
clear all
clc
A = [1,-1,-1,-1;
    -1,1,-1,-1;
    -1,-1,1,-1;
    -1,-1,-1,1]
% admittance matrix
Y = [-14.5i,8i,4i,2.5i;
    8i,-17i,4i,5i;
    4i,4i,-8.8i,0;
    2.5i,5i,0,-8.3i]

% current injected into the system
I = [0;
    0;
    -1i
    ((-17*sqrt(2))/50)*(1+i)]

%calculate for busbar voltage
% V=inv(Y)*I
V = Y\I

%calculate for line currents y(i,j)=Y.*A
%I_ij=Y_ij (V_i-V_j); I_ji=Y_ji (V_j-V_i)
y=[];
y = Y.*A;
for i = 1:4
    for j = 1:4
    Iline(i,j)=y(i,j)*(V(i,1)-V(j,1));
    end
end
Iline

%calculat for complex power flows
% S_ij=V_i I_ij^*=P_ij+jQ_ij; S_ji=V_j I_ji^*=P_ji+jQ_ji
S=[];
for i = 1:4
    for j = 1:4
        S(j,i)=V(j,1)*conj(Iline(j,i));
    end
end
S
```