EE 310: Power Systems Lab

Term Project – Power World & PSCAD

Group 17

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TP#17

Build and simulate IEEE 5 bus system in PSCAD as well as in POWERWORLD Simulator using the datasheet provided along with the problem. Perform the following tasks:

A. Analyze the impact of contingency using the Generator Shift Factor (GSF), Line Outage Distribution Factor (LODF), PI based ranking of various components etc.

B. Identify the weak buses in the system from part (a) and increase the active power (P) and reactive power (Q) demand at the top 2 weak load buses in the system. Plot the waveforms for fundamental rms voltages, voltage angles, injected active powers (P_i), injected reactive powers (Q_i) as well as PV curve at these load buses.

C. Identify the weak line in the system from part (a). Simulate a case study in which due to 3 phase fault at this critical line, the line gets opened. Plot the waveforms for fundamental rms voltages, voltage angles, injected active powers (P_i) as well as injected reactive powers (Q_i) at these load buses.

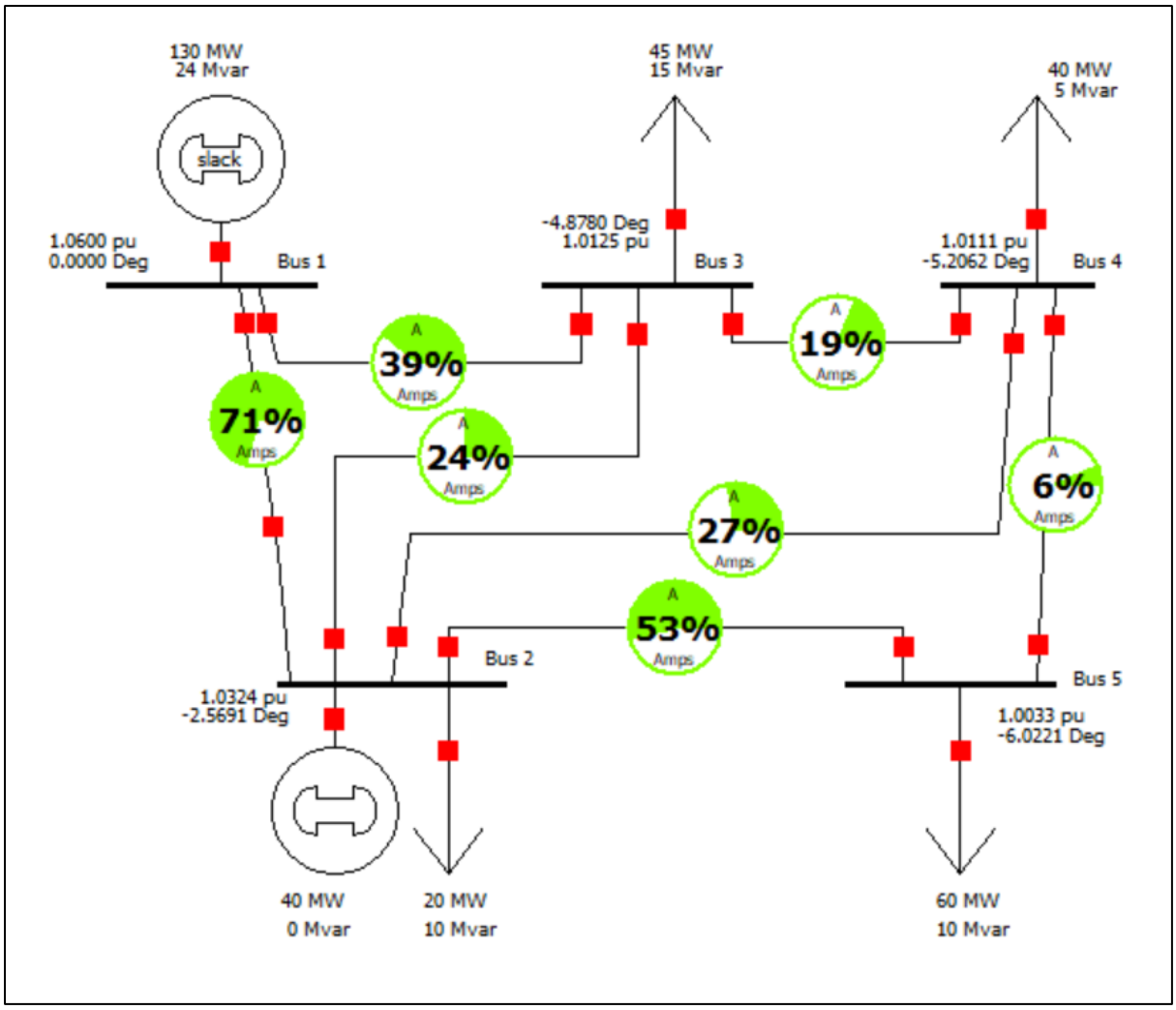
D. Now, let's assume that PMUs are installed at these weak load buses to measure rms voltages and angles. Export the data of these buses (For the case studies in both part (b) and part (c) of the question) with the sampling time of (1/60) sec.

Solution:

In this project, first we need to analyse the flow of power and observe the effect of different contingencies on the different elements of the power system.

For, contingency analysis we used the power world software, and calculated the sensitivity factors like GSF (Generator Shift Factor) and LODF (Load Outage Distribution Factor). And observing these two factors, we classified the different buses as weak and strong based on their sensitivity to different contingencies.

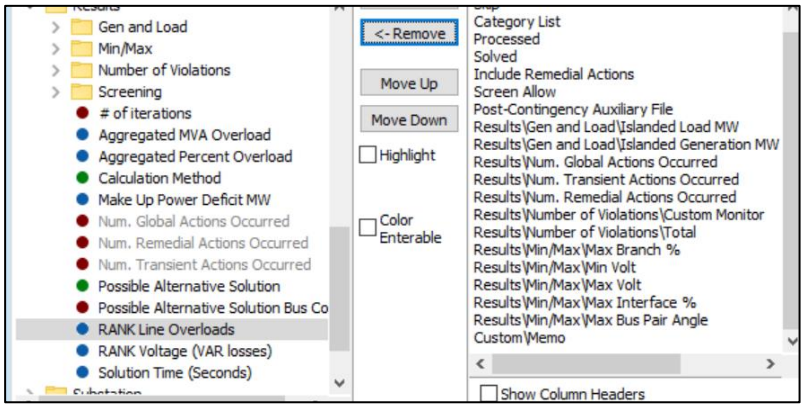
Contingency Analysis



Circuit Diagram of IEEE – 5 bus system in Power World

Here, we can observe the flow of power in different lines, 1-2 line is 120 MW rated, whereas rest are 100 MW rated.

Now, for observing the pi-based ranking of different buses based on different contingencies, we went to contingency analysis, and added Rank Line Overloads to know PI based ranking.



	Name	RANK Overload	Skip
1	L_000001Bus1-000002Bus2C1	3.1	NO
2	L_000001Bus1-000003Bus3C1	1.5	NO
3	L_000003Bus3-000002Bus2C1	1.1	NO
4	L_000004Bus4-000002Bus2C1	1.2	NO
5	L_000002Bus2-000005Bus5C1	1.8	NO
6	L_000003Bus3-000004Bus4C1	1.1	NO
7	L_000004Bus4-000005Bus5C1	1.0	NO
8	S_000002Bus21	0.9	NO
9	S_000003Bus31	0.6	NO
10	S_000004Bus41	0.5	NO
11	S_000005Bus51	0.3	NO
12	G_000001Bus1U1	0.7	NO
13	G_000002Bus2U1	1.4	NO

PI based Ranking of different contingencies

Effect of contingency no 1 – 2

	Category	Element	Value	Limit	Percent	Area Name Assoc.	Nom kV Assoc.
1	Branch MVA	Bus 1 (1) -> Bus 3 (3) CKT 1 at Bus 1	202.47	100.00	202.47	1	138.0
2	Bus Low Volts	Bus 2 (2)	0.6559	0.9000	72.87	1	138.0
3	Bus Low Volts	Bus 3 (3)	0.6933	0.9000	77.04	1	138.0
4	Bus Low Volts	Bus 4 (4)	0.6755	0.9000	75.06	1	138.0
5	Bus Low Volts	Bus 5 (5)	0.6232	0.9000	69.24	1	138.0

Effect of contingency no 2 – 5

	Category	Element	Value	Limit	Percent	Area Name Assoc.	Nom kV Assoc.
1	Bus Low Volts	Bus 5 (5)	0.8843	0.9000	98.25	1	138.0

We also analysed the sensitivity using GSF and LODF, by calculating for each buses, and we got the following data.

GSF Analysis

	Number	Name	Area Num	Area Name	P Sensitivity
1	5	Bus 5	1	1	0.713
2	4	Bus 4	1	1	0.500
3	1	Bus 1	1	1	0.421
4	2	Bus 2	1	1	0.421
5	3	Bus 3	1	1	0.386

LODF Analysis

	From Numbe	From Name	To Numbe	To Name	Circuit	MW From	Bus 1 (1) TO Bus 2 (2) CKT 1	Bus 1 (1) TO Bus 3 (3) CKT 1	Bus 3 (3) TO Bus 2 (2) CKT 1	Bus 4 (4) TO Bus 2 (2) CKT 1	Bus 2 (2) TO Bus 5 (5) CKT 1	Bus 3 (3) TO Bus 4 (4) CKT 1	Bus 4 (4) TO Bus 5 (5) CKT 1
1	1	Bus 1	2	Bus 2	1	88.746	-100.00	100.00	45.45	36.36	-18.18	54.55	18.18
2	1	Bus 1	3	Bus 3	1	41.003	100.00	-100.00	-45.45	-36.36	18.18	-54.55	-18.18
3	3	Bus 3	2	Bus 2	1	-24.277	33.33	-33.33	-100.00	44.44	-22.22	66.67	22.22
4	4	Bus 4	2	Bus 2	1	-27.423	26.87	-26.87	44.78	-100.00	-28.36	-71.64	28.36
5	2	Bus 2	5	Bus 5	1	54.772	-20.93	20.93	-34.88	-44.19	-100.00	55.81	100.00
6	3	Bus 3	4	Bus 4	1	19.026	37.50	-37.50	62.50	-66.67	33.33	-100.00	-33.33
7	4	Bus 4	5	Bus 5	1	6.413	20.93	-20.93	34.88	44.19	100.00	-55.81	-100.00

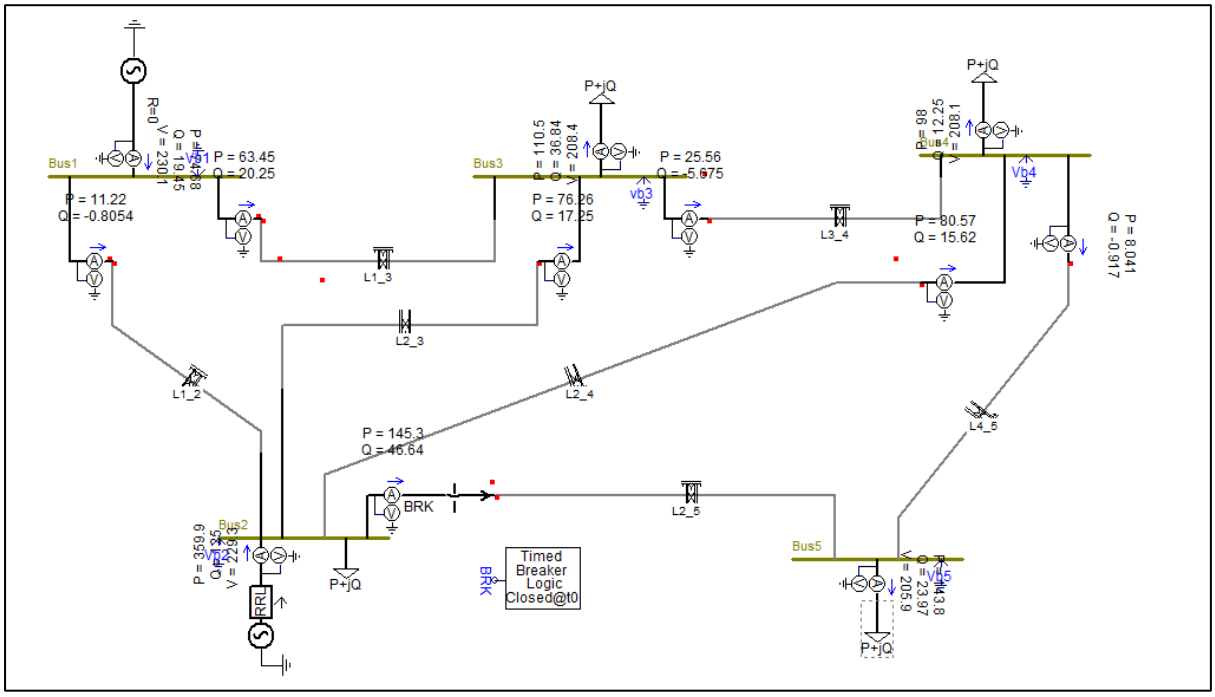
Inference from Power World:

Seeing the GSF, we can conclude that bus number 5, and 4 are the weakest because they are the most sensitive to the contingencies, and has the maximum voltage drop across them.

And beside this, line number 1-2 and 2-5 are the weakest because they have the highest PI ranking that means they are causing the much effect of the remaining circuit, if they got break.

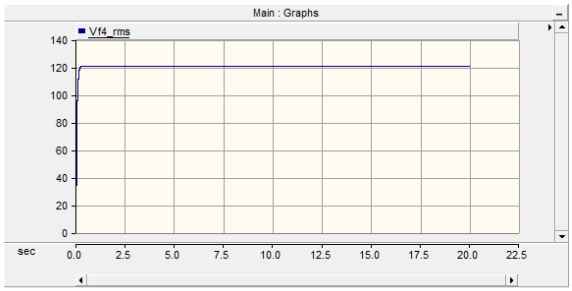
Line 1-2, pi ranking 3.1 and line 2-5, pi ranking 1.8

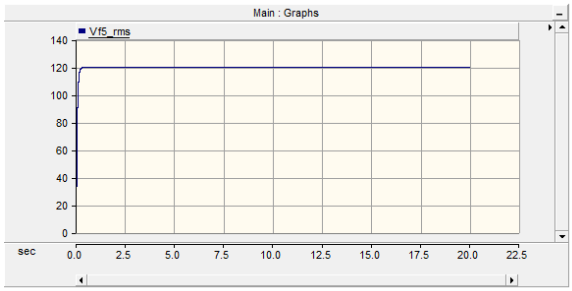
Analysis in PSCAD

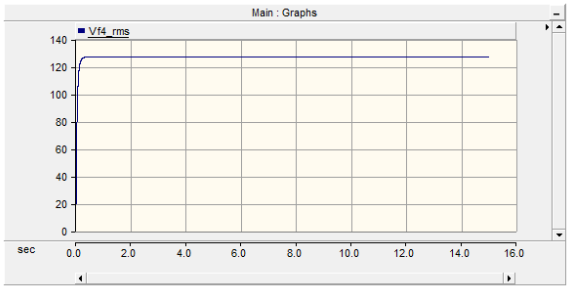


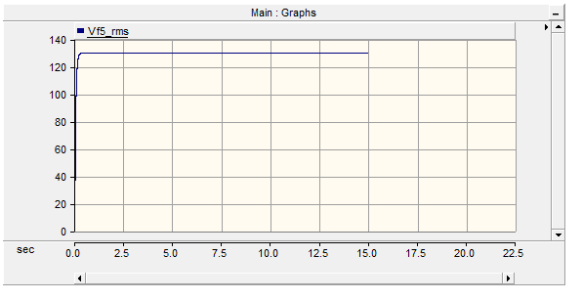
Circuit Diagram of IEEE – 5 bus system in PSCAD

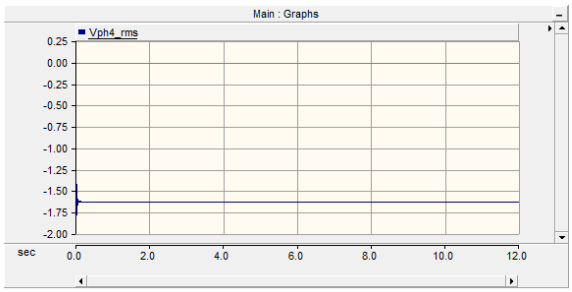
Here, are the graphs for fundamental rms voltage of weak buses i.e., 4 and 5, and also the net real and reactive power injected at these buses.

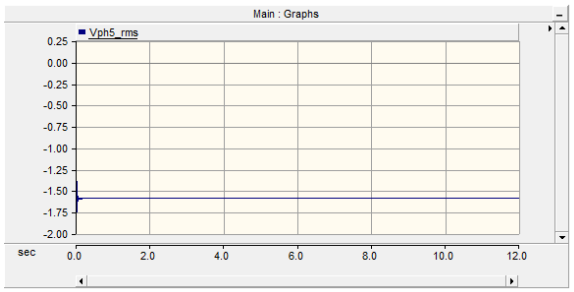


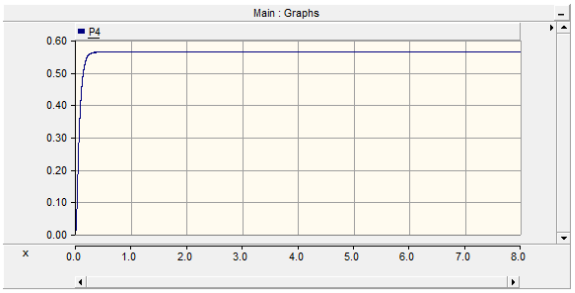


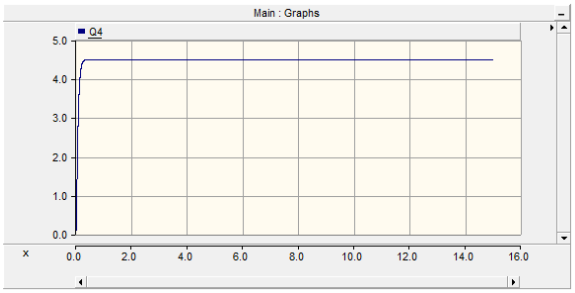


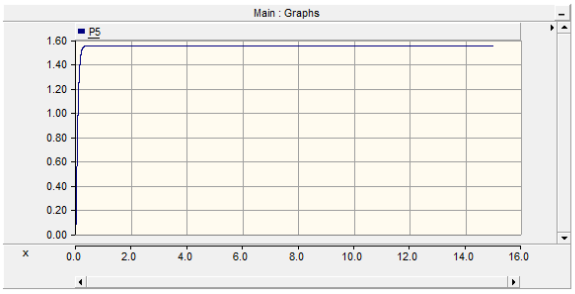


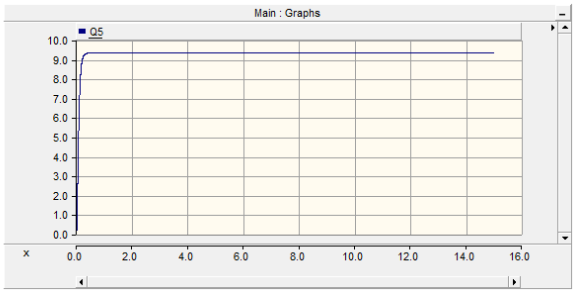




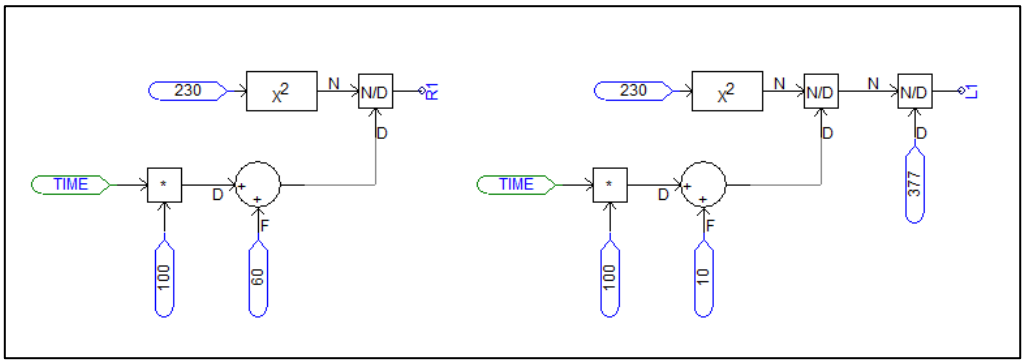




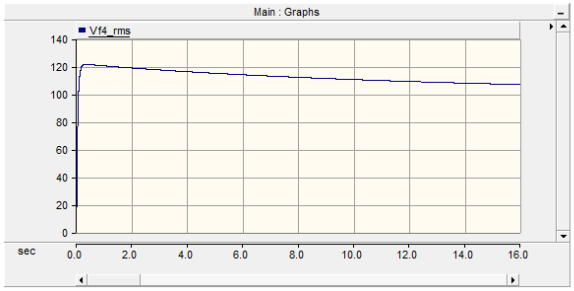


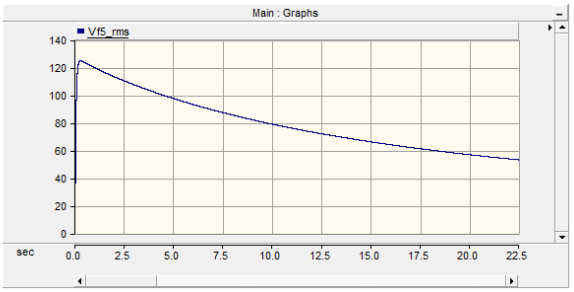


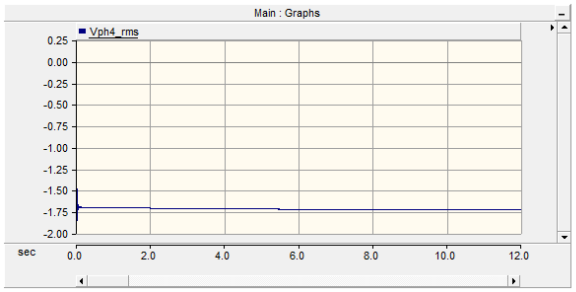
Now, as per the second part of the problem statement, increase the injected real and reactive power at these weak buses, using variable RL load and calculating R and L so that P and Q will be increasing with time.

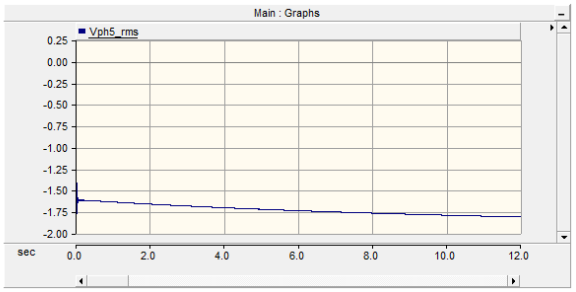


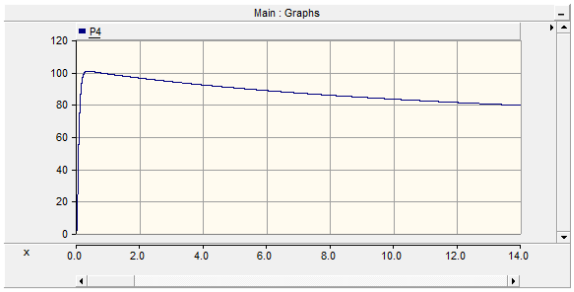
Injecting power at bus 5 by increasing R and L of the load.

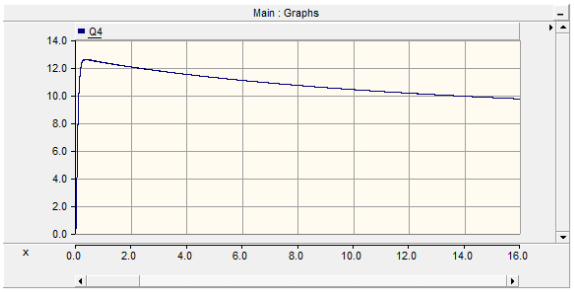


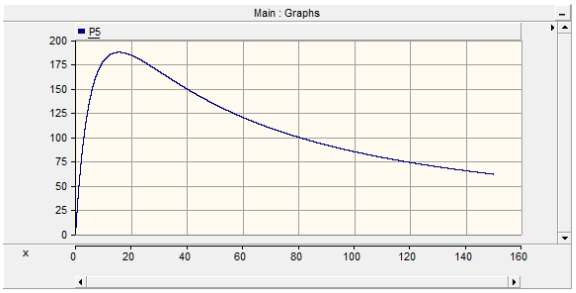


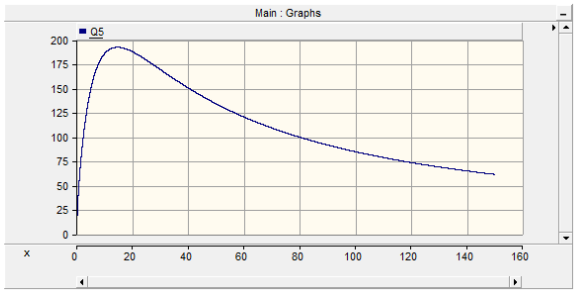


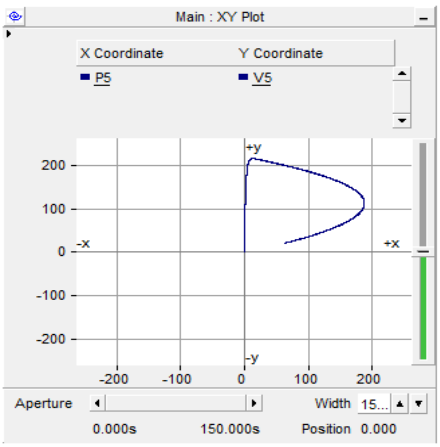


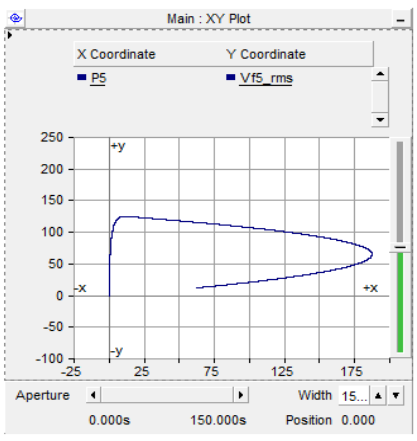




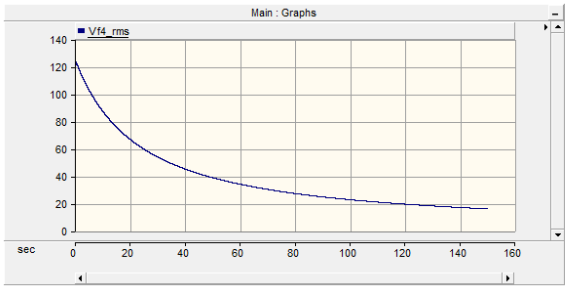


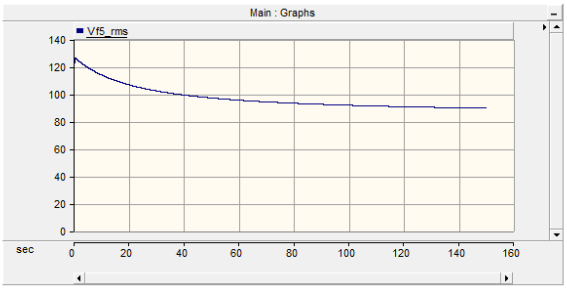


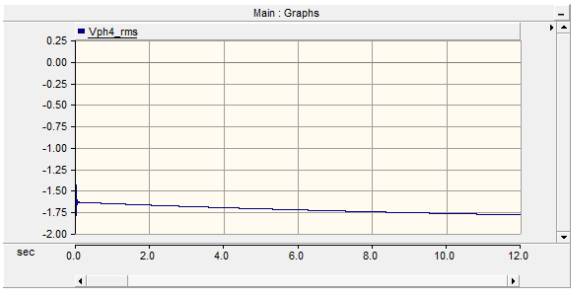


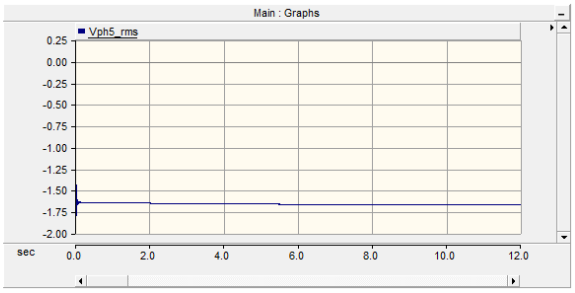


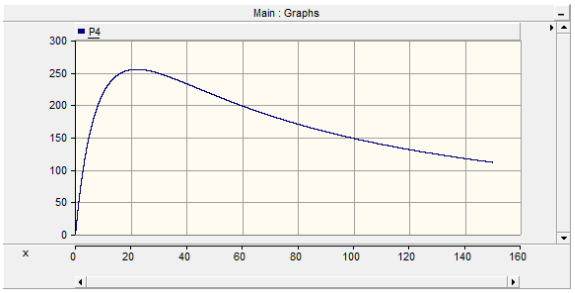
Injecting power at bus 4 by increasing R and L of the load.

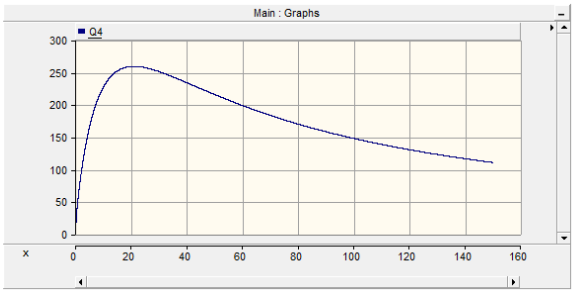


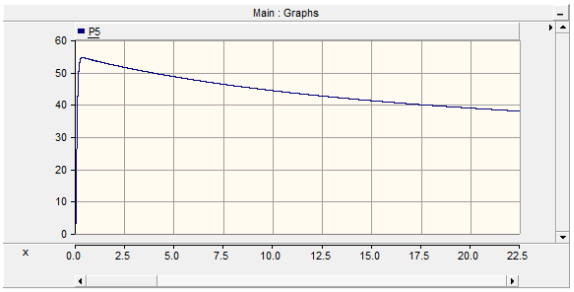


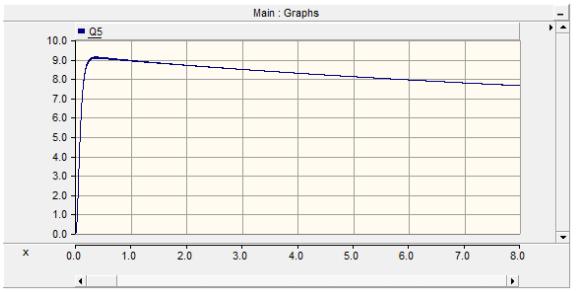


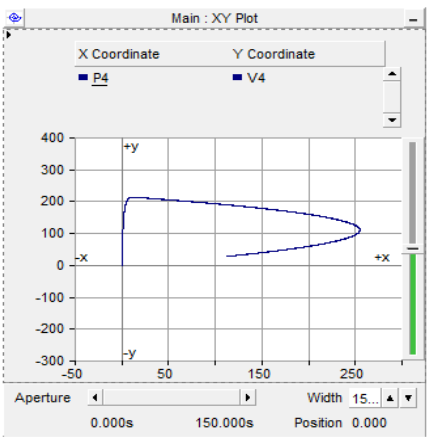


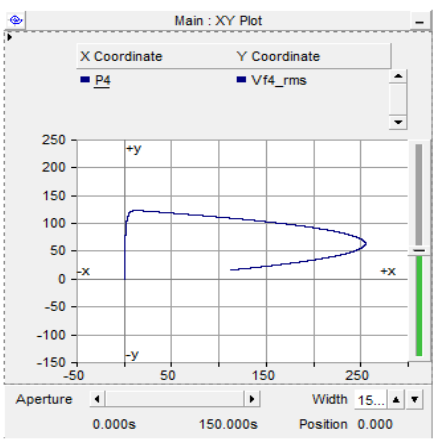




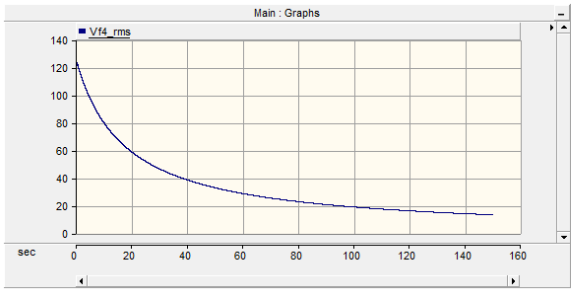


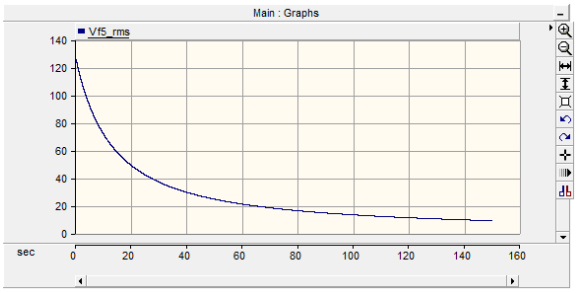


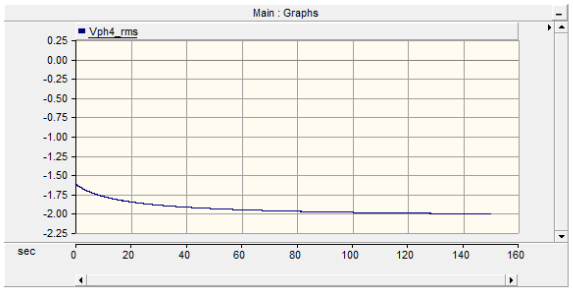


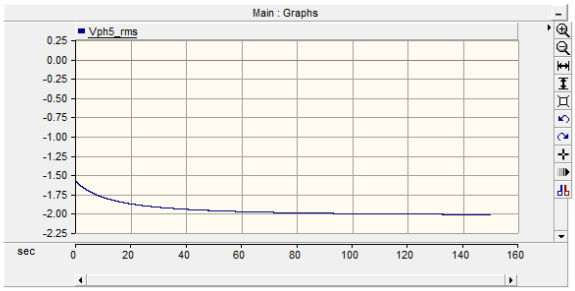


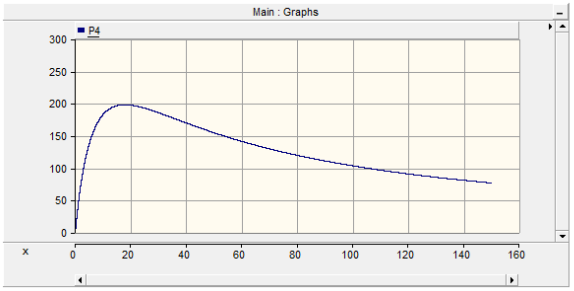
Injecting power at both 4 and 5 buses simultaneously.

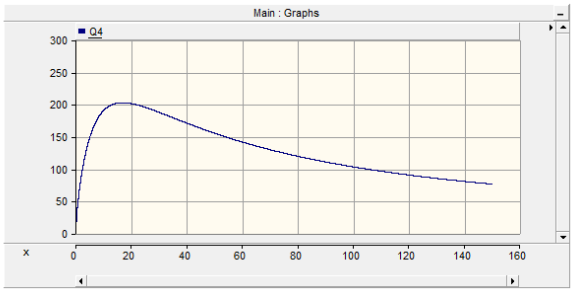


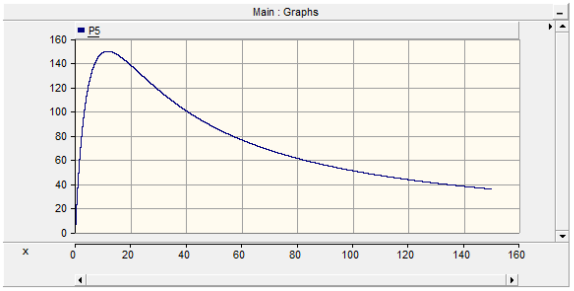


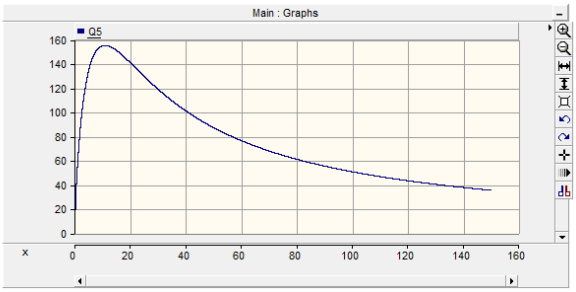


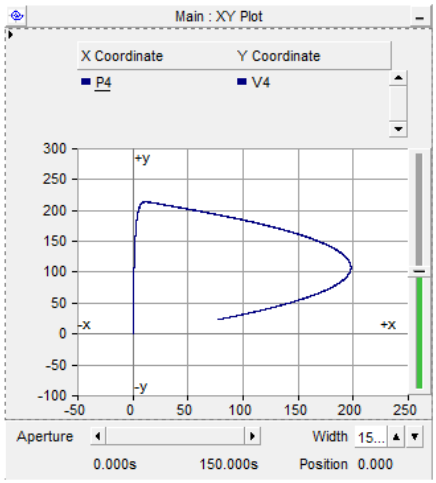


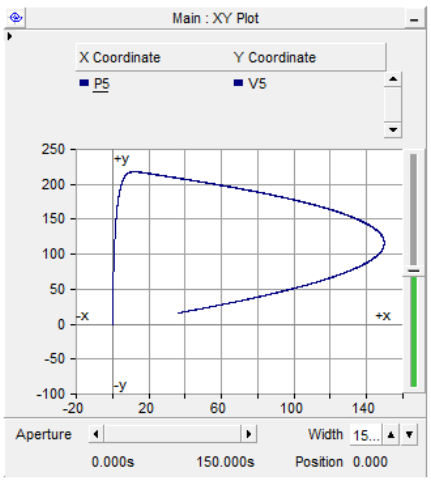


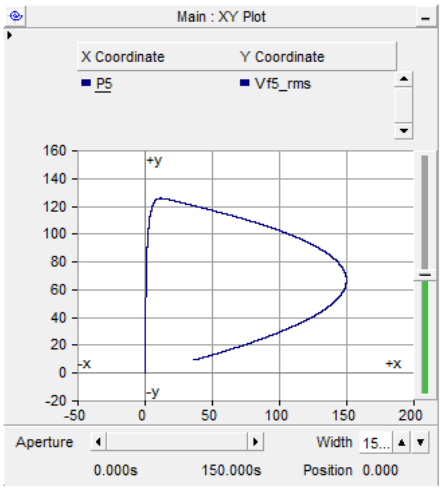


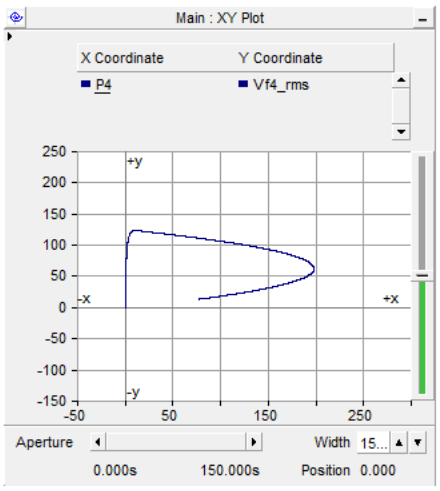








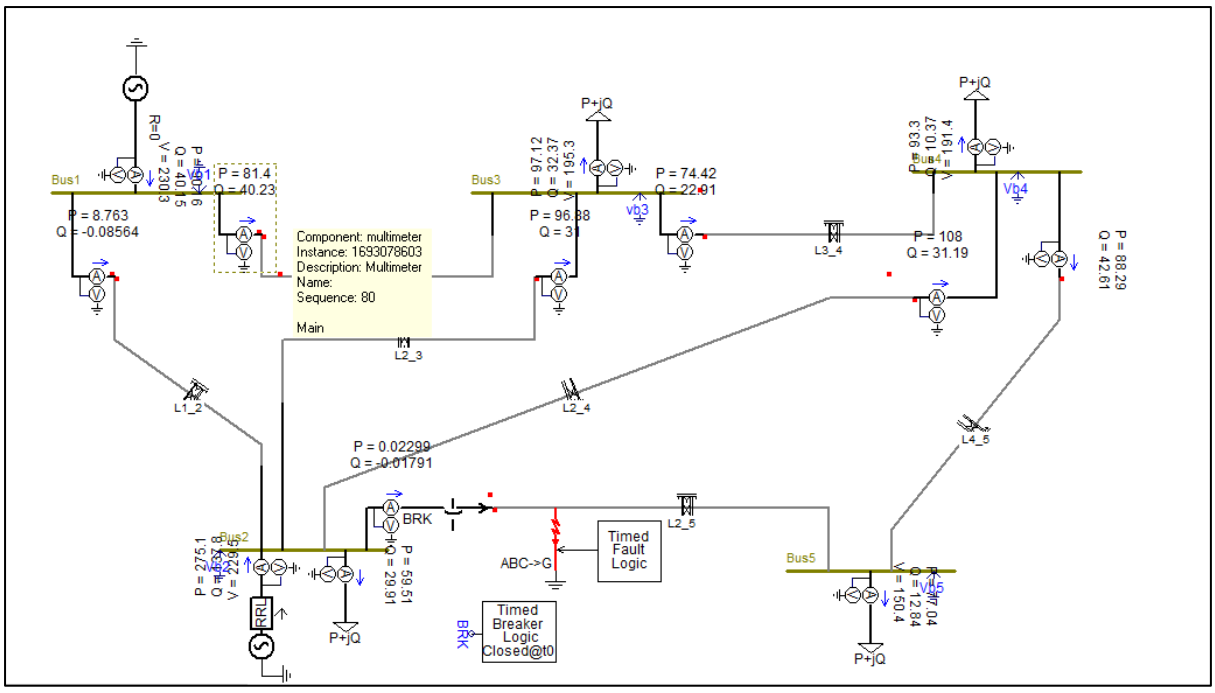


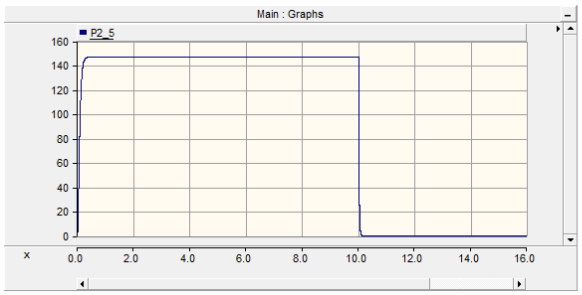


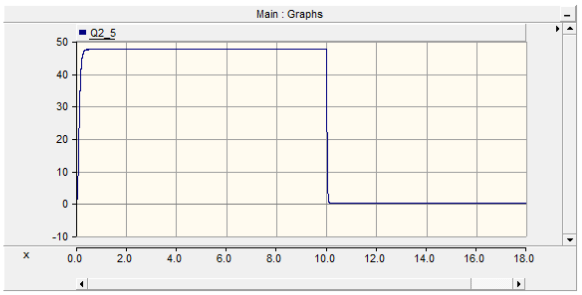
Now, we observe that when we increase the load demand, by varying R and L we see that when power demand increases the voltage of that bus decreases along with its phase and after reaching the maximum, the power starts decreasing due to voltage collapse, occurred at the right most point of the PV Curve obtained (Critical Point of Voltage Collapse). And we observe that voltage drop when we increase power is much more on these weak buses (4 and 5) than any other bus.

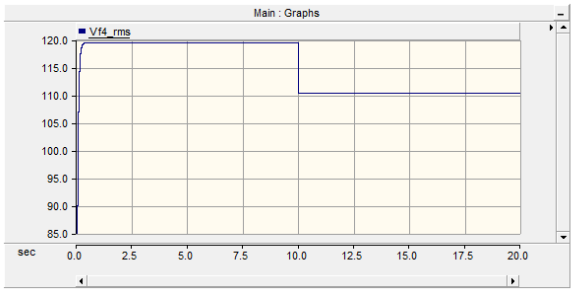
Moving on to the third part of our problem statement, we applied the fault and breaker circuit to open the line at the time fault occurs.

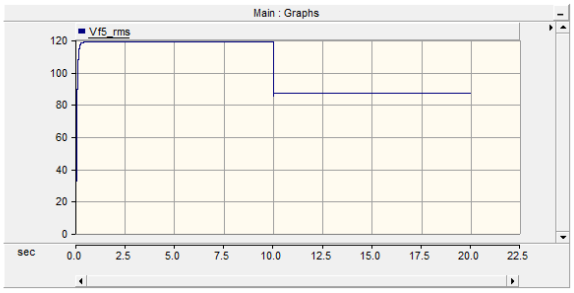
Applying fault to the sensitive bus 2 - 5

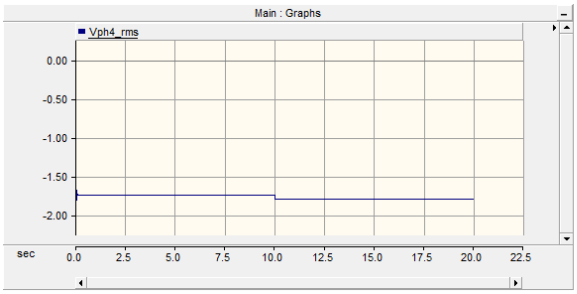


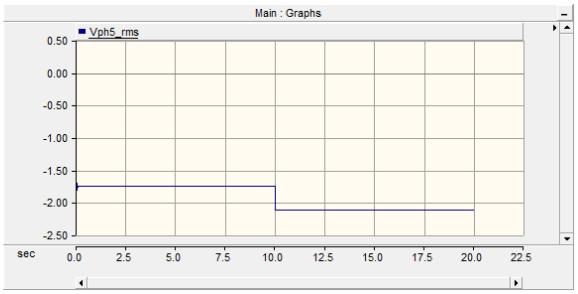

Main : Graphs
P2_5
160
140
120
100
80
60
40
20
0
x
0.0 2.0 4.0 6.0 8.0 10.0 12.0 14.0 16.0

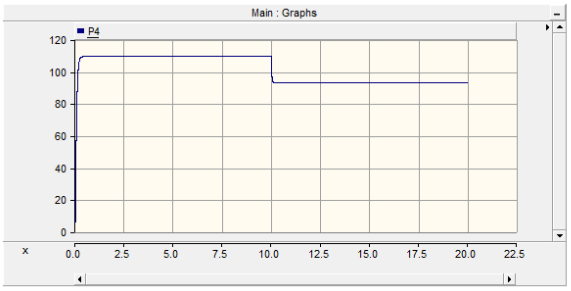

Main : Graphs
Q2_5
50
40
30
20
10
0
-10
x
0.0 2.0 4.0 6.0 8.0 10.0 12.0 14.0 16.0 18.0

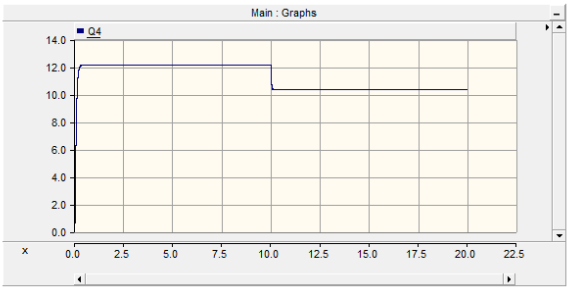

Main : Graphs
Vf4_rms
120.0
115.0
110.0
105.0
100.0
95.0
90.0
85.0
sec
0.0 2.5 5.0 7.5 10.0 12.5 15.0 17.5 20.0

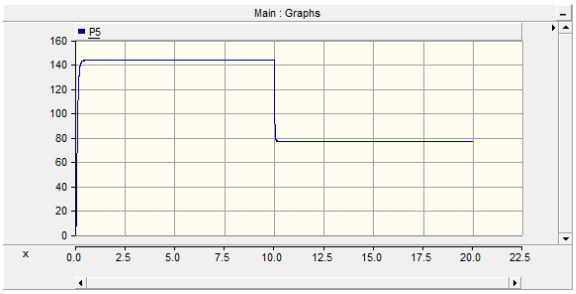

Main : Graphs
Vf5_rms
120
100
80
60
40
20
0
sec
0.0 2.5 5.0 7.5 10.0 12.5 15.0 17.5 20.0 22.5

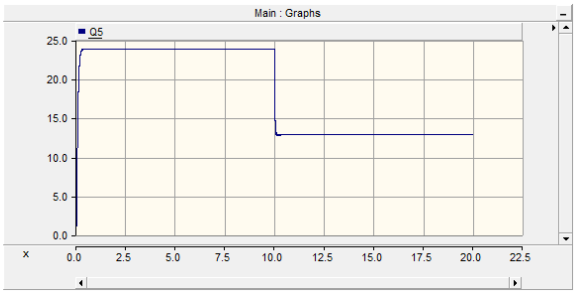

Main : Graphs
Vph4_rms
0.00
-0.50
-1.00
-1.50
-2.00
sec
0.0 2.5 5.0 7.5 10.0 12.5 15.0 17.5 20.0 22.5

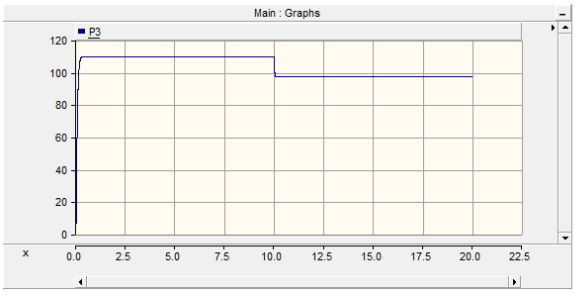

Main : Graphs
Vph5_rms
0.50
0.00
-0.50
-1.00
-1.50
-2.00
-2.50
sec
0.0 2.5 5.0 7.5 10.0 12.5 15.0 17.5 20.0 22.5

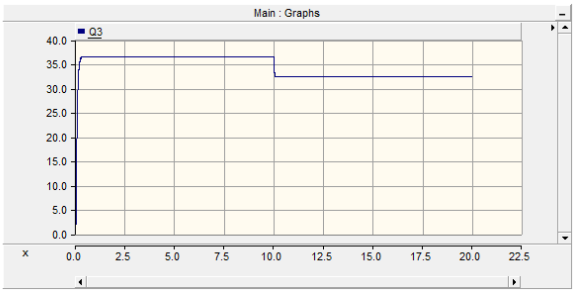

Main : Graphs
P4
120
100
80
60
40
20
0
x
0.0 2.5 5.0 7.5 10.0 12.5 15.0 17.5 20.0 22.5

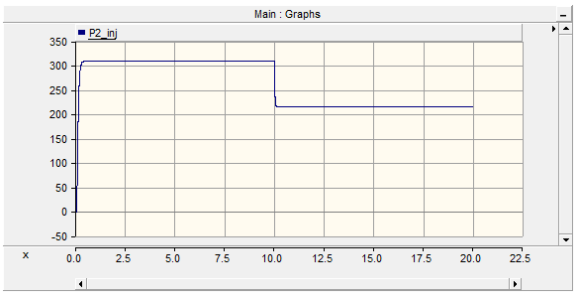

Main : Graphs
Q4
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
x
0.0 2.5 5.0 7.5 10.0 12.5 15.0 17.5 20.0 22.5

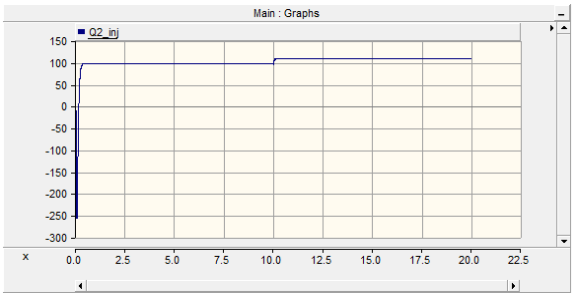

Main : Graphs
P5
160
140
120
100
80
60
40
20
0
x
0.0 2.5 5.0 7.5 10.0 12.5 15.0 17.5 20.0 22.5

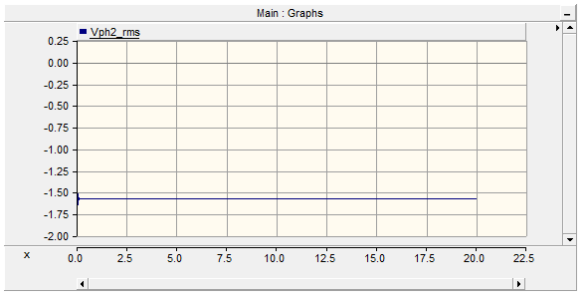

Main : Graphs
Q5
25.0
20.0
15.0
10.0
5.0
0.0
x
0.0 2.5 5.0 7.5 10.0 12.5 15.0 17.5 20.0 22.5

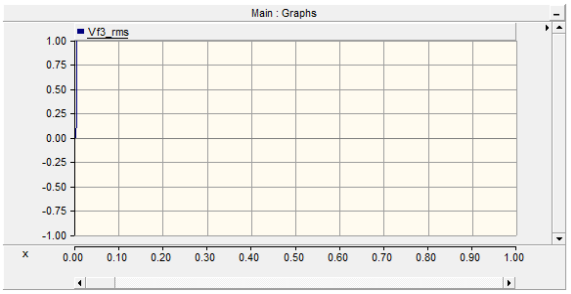

Main : Graphs
P3
120
100
80
60
40
20
0
x
0.0 2.5 5.0 7.5 10.0 12.5 15.0 17.5 20.0 22.5

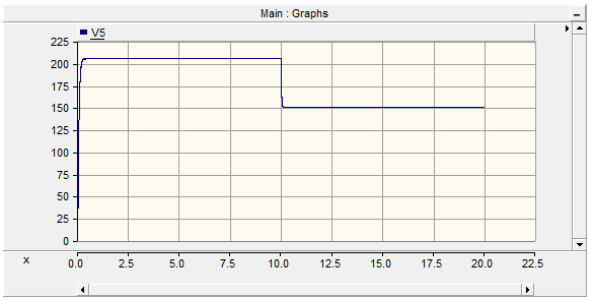

Main : Graphs
Q3
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
x
0.0 2.5 5.0 7.5 10.0 12.5 15.0 17.5 20.0 22.5

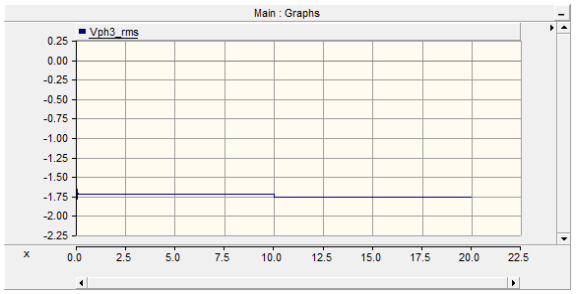


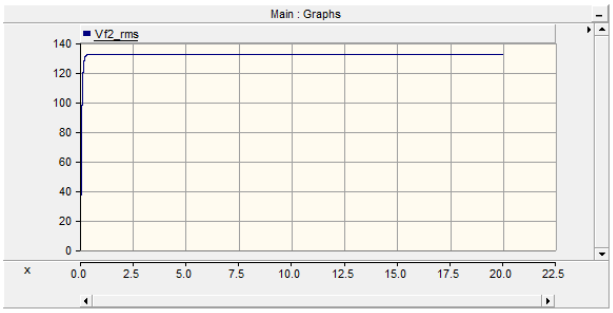




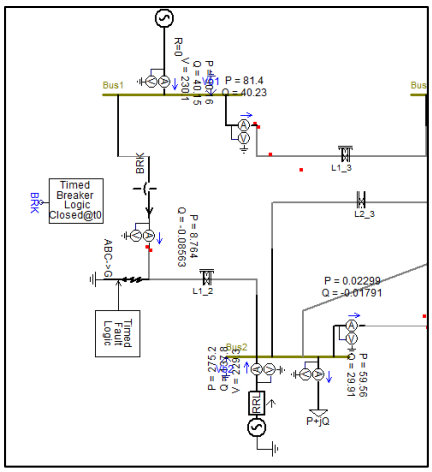


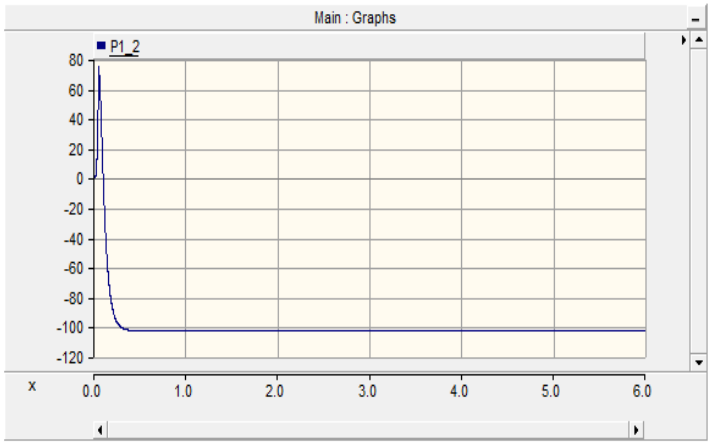


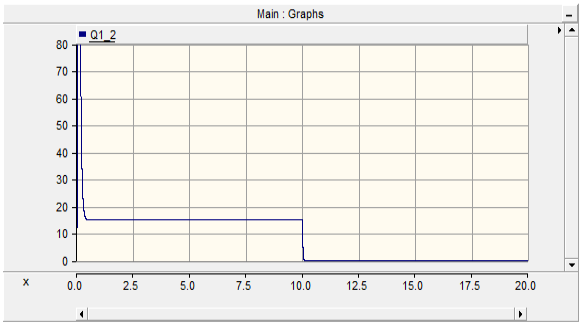


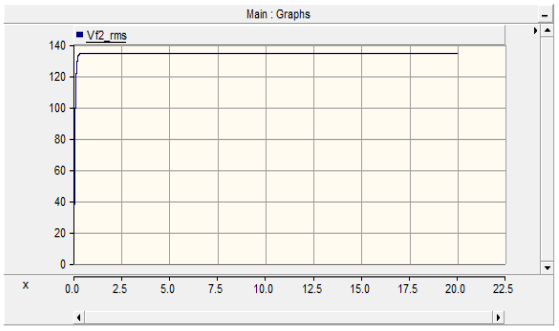


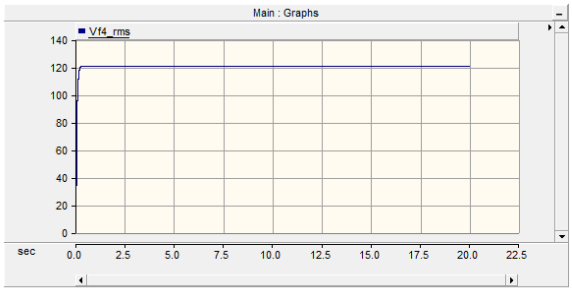
Applying fault on line 1-2

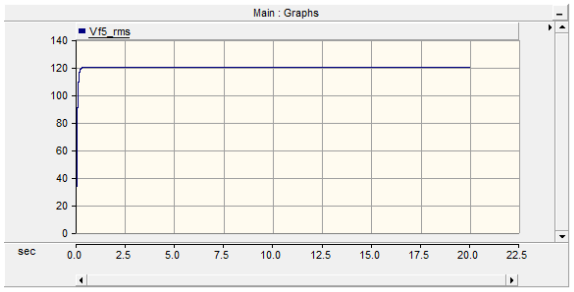


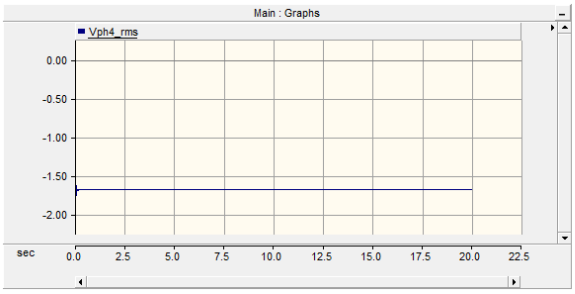


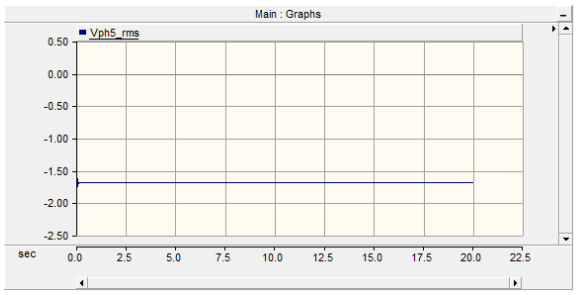

Main : Graphs
Q1_2
80
70
60
50
40
30
20
10
0
x
0.0
2.5
5.0
7.5
10.0
12.5
15.0
17.5
20.0

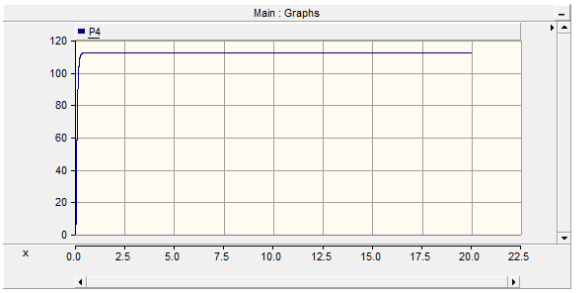

Main : Graphs
Vf2_rms
140
120
100
80
60
40
20
0
x
0.0
2.5
5.0
7.5
10.0
12.5
15.0
17.5
20.0
22.5

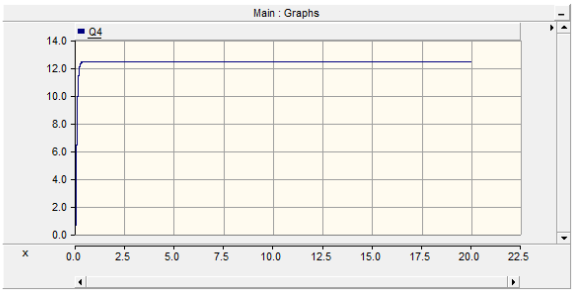

Main : Graphs
Vf4_rms
140
120
100
80
60
40
20
0
sec
0.0
2.5
5.0
7.5
10.0
12.5
15.0
17.5
20.0
22.5

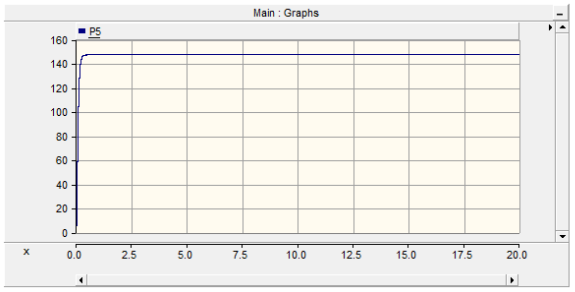

Main : Graphs
Vf5_rms
140
120
100
80
60
40
20
0
sec
0.0
2.5
5.0
7.5
10.0
12.5
15.0
17.5
20.0
22.5

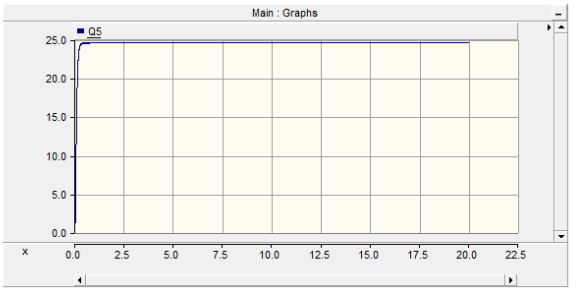

Main : Graphs
Vph4_rms
0.00
-0.50
-1.00
-1.50
-2.00
sec
0.0
2.5
5.0
7.5
10.0
12.5
15.0
17.5
20.0
22.5

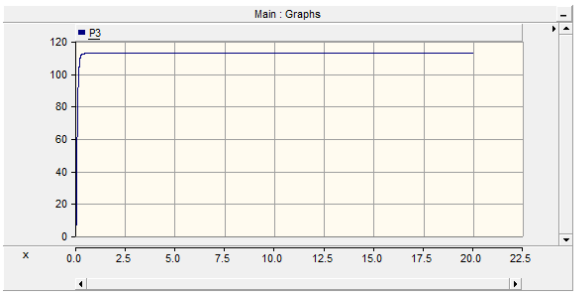

Main : Graphs
Vph5_rms
0.50
0.00
-0.50
-1.00
-1.50
-2.00
-2.50
sec
0.0
2.5
5.0
7.5
10.0
12.5
15.0
17.5
20.0
22.5

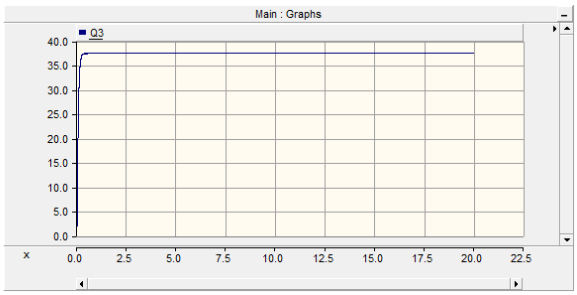

Main : Graphs
P4
120
100
80
60
40
20
0
x
0.0
2.5
5.0
7.5
10.0
12.5
15.0
17.5
20.0
22.5

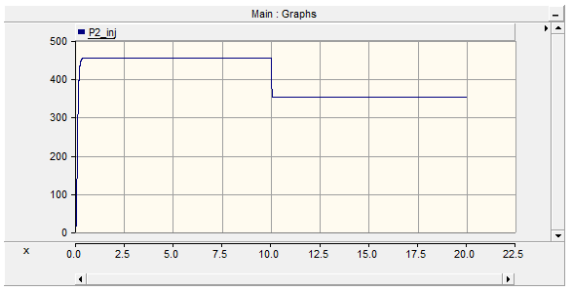

Main : Graphs
Q4
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
x
0.0
2.5
5.0
7.5
10.0
12.5
15.0
17.5
20.0
22.5

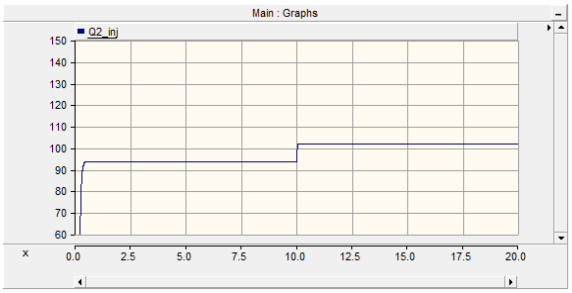

Main : Graphs
P5
160
140
120
100
80
60
40
20
0
x
0.0
2.5
5.0
7.5
10.0
12.5
15.0
17.5
20.0

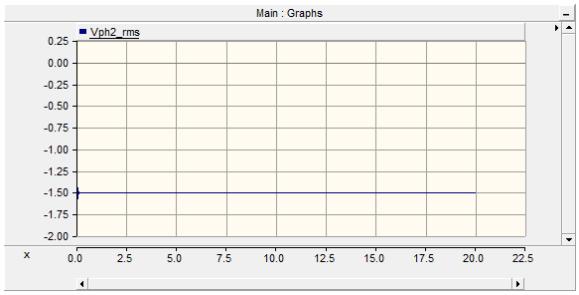

Main : Graphs
Q5
25.0
20.0
15.0
10.0
5.0
0.0
x
0.0
2.5
5.0
7.5
10.0
12.5
15.0
17.5
20.0
22.5

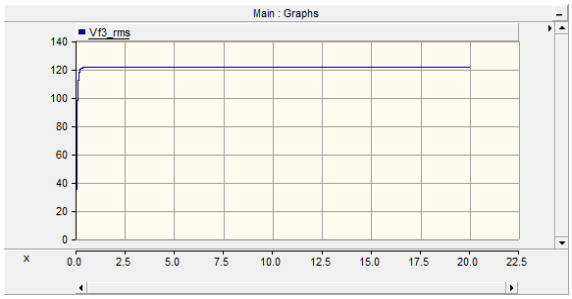


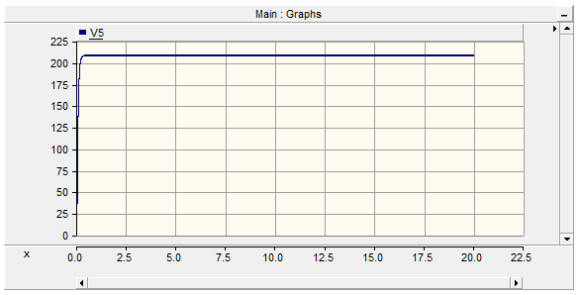


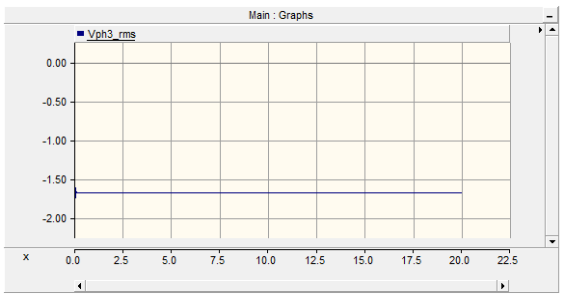












In this, we analysed how on applying load at these weak lines makes changes in real and reactive power injected at different buses. Also, we observed how, the 2-5 bus breakage cause almost rise in every other line and drop in the bus voltages. In case of 1-2 breakage, we observed that there are not significant drops and overloading because power loss due to fault/breakage is met by the generator at bus 2 and there are minor changes in power flow of different line, and voltage drops are also minimal. But if we limit the generator 2 power then line 1 to 2 becomes very important because there will be very less power from slack to 2, 3, and 5 buses.

Also, we exported the data of voltages and angles from these weak buses using PMUs into a excel sheet. We can refer that data to analyse the effect of contingencies over these weak buses.

Conclusion:

In conclusion, this report presents the implementation of an IEEE 5-bus system in Power World and the subsequent analysis of contingency and sensitivity. Additionally, the system was simulated in PSCAD to analyze the effects of contingencies and faults on various buses, employing different plots to visualize injected power and fundamental RMS voltage.

The utilization of Power World allowed for a comprehensive investigation into contingency and sensitivity analysis. By considering various system conditions, such as generator outages, transmission line failures, and load variations, the study explored the system's resilience and identified critical components that significantly impact its stability and reliability.

Furthermore, the integration of PSCAD provided a detailed examination of the effects of contingencies and faults on individual buses. Through the analysis of injected power at each bus and fundamental RMS voltage, the study identified vulnerable buses that are prone to voltage drops, excessive power flow, or other detrimental consequences due to contingencies and faults.