Bangladesh University of Engineering and Technology

Report on Project

Course No: EEE 306
Course Title: Power System I Laboratory

Project Title

Investigating the effect of HVDC connection and large industrial loads in IEEE 39-bus network

Report Submitted by:

Group – 6 (A2)

ID: 1706061 Name: Swadesh Vhakta
ID: 1706062 Name: Imtiaz Ahmed
ID: 1706063 Name: Tamim Ahmed
ID: 1706064 Name: Sadat Tahmeed Azad
ID: 1706065 Name: MD. Mahadi Hasan

EEE 17, Section A2
Level 3, Term 1

Introduction

In this project, we are given the line diagram and data for different components (bus, line, fixed tap transformers, generator and static load) for the IEEE 39 bus (New England) test system, which is a is well known as 10-machine New-England Power System. The nominal frequency is 50 Hz. This case is used to study simultaneous damping of local and inter-are modes in a system with a highly symmetrical structure.

We are required to fast transform a load flow analysis, followed by a fault analysis at the generator buses. Then, in task 3, we make some specific generators emulate PV (Photovoltaic) generators, and perform the load flow again.

In task 4 and 5, we attach an induction motor to model an industrial plant, which greatly reduces the power factor of the system and causes overload, and then compensate for it using static VAR generator and distributed swing. Thus, we are familiarized with the basic operations of a typical real-time large scale power network.

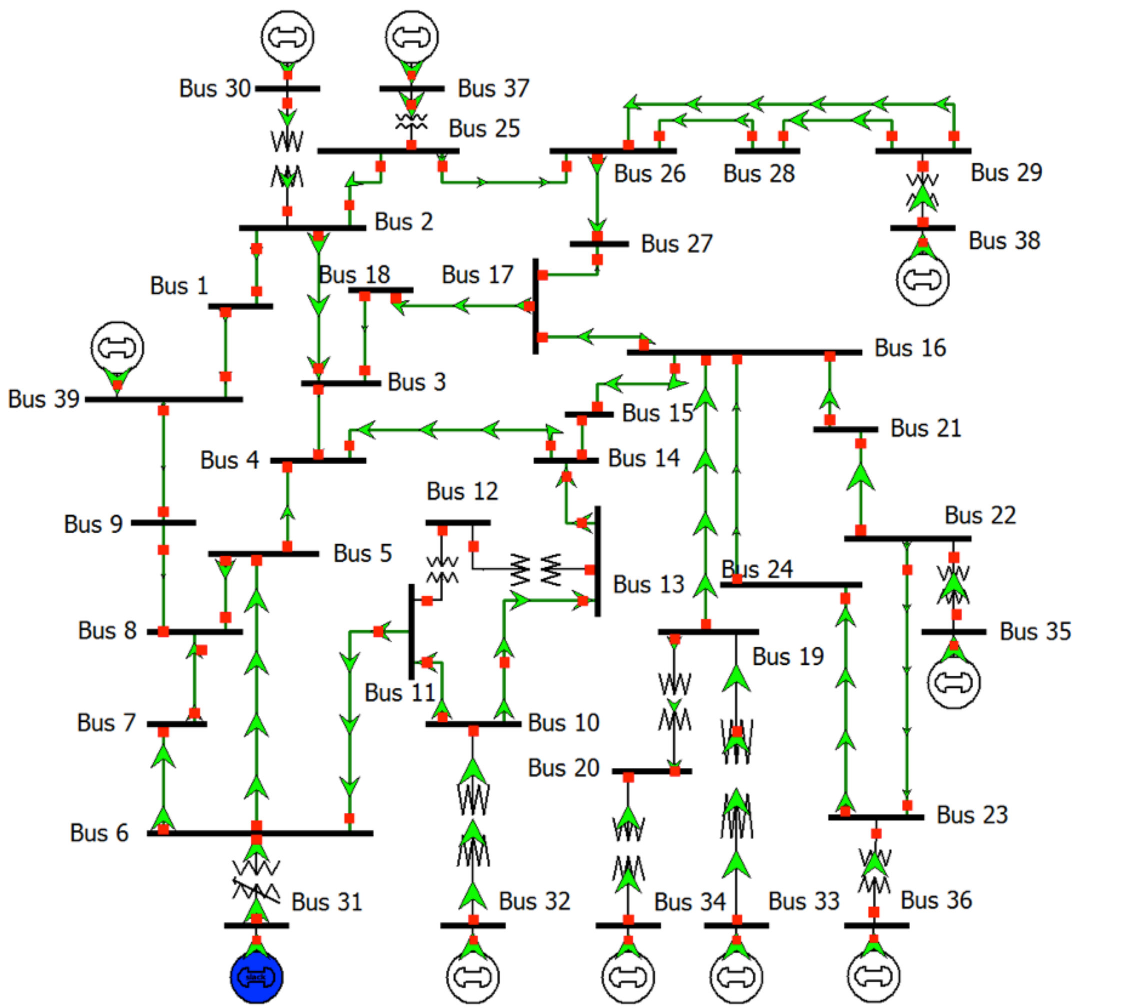
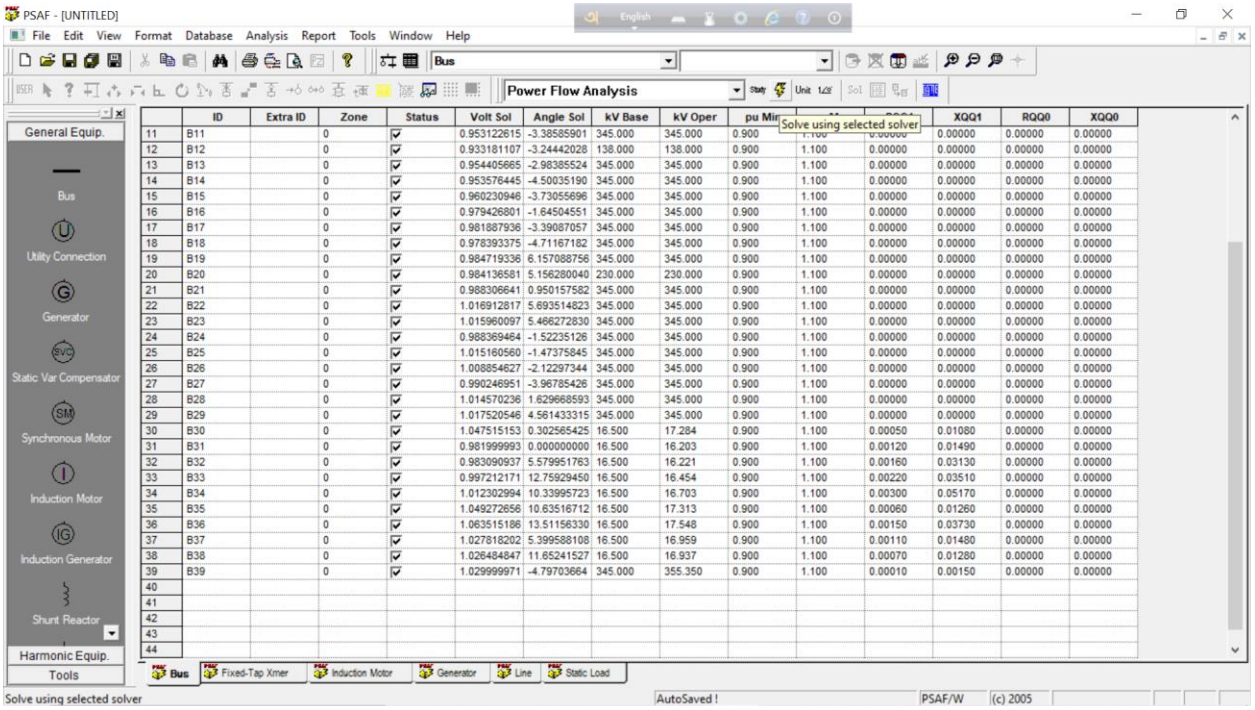


Figure 1: IEEE 39-Bus System

Task 1

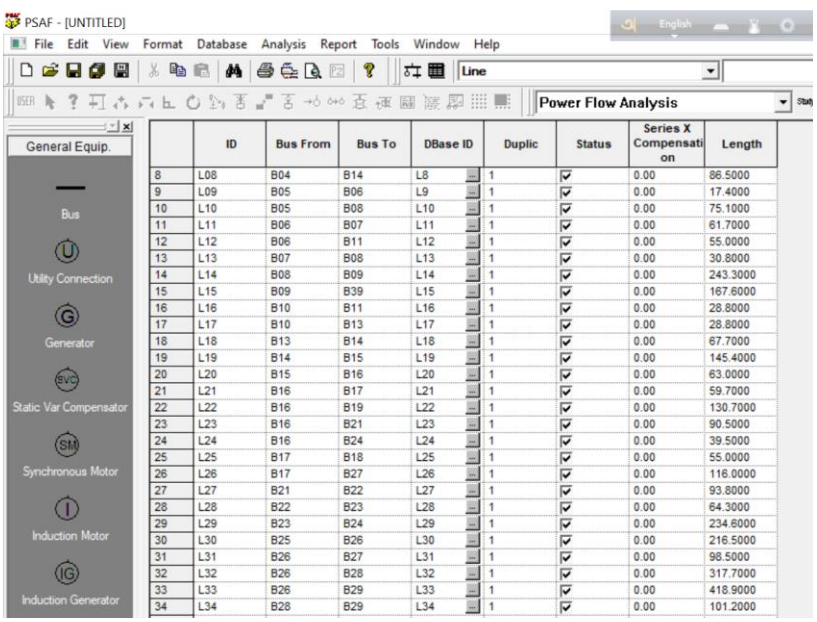
The given data are entered into PSAF in tabular form as below, the IDs are exactly as given except for the loads, which were changed from L to LD to differentiate from the lines.

Bus Data



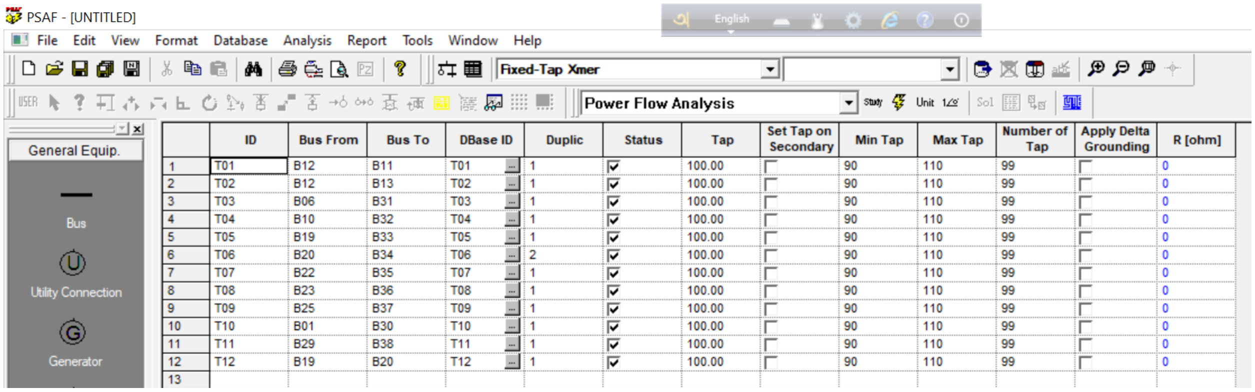
	ID	Extra ID	Zone	Status	Volt Sol	Angle Sol	kV Base	kV Oper	pu Min	[illegible]	[illegible]	XQQ1	RQQ0	XQQ0
11	B11		0	✓	0.953122615	-3.38585901	345.000	345.000	0.900	[illegible]	[illegible]	0.00000	0.00000	0.00000
12	B12		0	✓	0.933181107	-3.24442028	138.000	138.000	0.900	1.100	0.00000	0.00000	0.00000	0.00000
13	B13		0	✓	0.954405665	-2.98385524	345.000	345.000	0.900	1.100	0.00000	0.00000	0.00000	0.00000
14	B14		0	✓	0.953576445	-4.50035190	345.000	345.000	0.900	1.100	0.00000	0.00000	0.00000	0.00000
15	B15		0	✓	0.960230946	-3.73055696	345.000	345.000	0.900	1.100	0.00000	0.00000	0.00000	0.00000
16	B16		0	✓	0.979426801	-1.64504551	345.000	345.000	0.900	1.100	0.00000	0.00000	0.00000	0.00000
17	B17		0	✓	0.981887936	-3.39087057	345.000	345.000	0.900	1.100	0.00000	0.00000	0.00000	0.00000
18	B18		0	✓	0.978393375	-4.71167182	345.000	345.000	0.900	1.100	0.00000	0.00000	0.00000	0.00000
19	B19		0	✓	0.984719336	6.157088756	345.000	345.000	0.900	1.100	0.00000	0.00000	0.00000	0.00000
20	B20		0	✓	0.984136581	5.156280040	230.000	230.000	0.900	1.100	0.00000	0.00000	0.00000	0.00000
21	B21		0	✓	0.988306641	0.950157582	345.000	345.000	0.900	1.100	0.00000	0.00000	0.00000	0.00000
22	B22		0	✓	1.016912817	5.693514823	345.000	345.000	0.900	1.100	0.00000	0.00000	0.00000	0.00000
23	B23		0	✓	1.015960097	5.466272830	345.000	345.000	0.900	1.100	0.00000	0.00000	0.00000	0.00000
24	B24		0	✓	0.988369464	-1.52235126	345.000	345.000	0.900	1.100	0.00000	0.00000	0.00000	0.00000
25	B25		0	✓	1.015160560	-1.47375845	345.000	345.000	0.900	1.100	0.00000	0.00000	0.00000	0.00000
26	B26		0	✓	1.008854627	-2.12297344	345.000	345.000	0.900	1.100	0.00000	0.00000	0.00000	0.00000
27	B27		0	✓	0.990246951	-3.96785426	345.000	345.000	0.900	1.100	0.00000	0.00000	0.00000	0.00000
28	B28		0	✓	1.014570236	1.629668593	345.000	345.000	0.900	1.100	0.00000	0.00000	0.00000	0.00000
29	B29		0	✓	1.017520546	4.561433315	345.000	345.000	0.900	1.100	0.00000	0.00000	0.00000	0.00000
30	B30		0	✓	1.047515153	0.302565425	16.500	17.284	0.900	1.100	0.00050	0.01080	0.00000	0.00000
31	B31		0	✓	0.981999993	0.000000000	16.500	16.203	0.900	1.100	0.00120	0.01490	0.00000	0.00000
32	B32		0	✓	0.983090937	5.579951763	16.500	16.221	0.900	1.100	0.00160	0.03130	0.00000	0.00000
33	B33		0	✓	0.997212171	12.75929450	16.500	16.454	0.900	1.100	0.00220	0.03510	0.00000	0.00000
34	B34		0	✓	1.012302994	10.33995723	16.500	16.703	0.900	1.100	0.00300	0.05170	0.00000	0.00000
35	B35		0	✓	1.049272656	10.63516712	16.500	17.313	0.900	1.100	0.00060	0.01260	0.00000	0.00000
36	B36		0	✓	1.063515186	13.51156330	16.500	17.548	0.900	1.100	0.00150	0.03730	0.00000	0.00000
37	B37		0	✓	1.027818202	5.399588108	16.500	16.959	0.900	1.100	0.00110	0.01480	0.00000	0.00000
38	B38		0	✓	1.026484847	11.65241527	16.500	16.937	0.900	1.100	0.00070	0.01280	0.00000	0.00000
39	B39		0	✓	1.029999971	-4.79703664	345.000	355.350	0.900	1.100	0.00010	0.00150	0.00000	0.00000
40														
41														
42														
43														
44														

Line Data



	ID	Bus From	Bus To	DBase ID	Duplic	Status	Series X Compensation	Length
8	L08	B04	B14	L8	1	✓	0.00	86.5000
9	L09	B05	B06	L9	1	✓	0.00	17.4000
10	L10	B05	B08	L10	1	✓	0.00	75.1000
11	L11	B06	B07	L11	1	✓	0.00	61.7000
12	L12	B06	B11	L12	1	✓	0.00	55.0000
13	L13	B07	B08	L13	1	✓	0.00	30.8000
14	L14	B08	B09	L14	1	✓	0.00	243.3000
15	L15	B09	B39	L15	1	✓	0.00	167.6000
16	L16	B10	B11	L16	1	✓	0.00	28.8000
17	L17	B10	B13	L17	1	✓	0.00	28.8000
18	L18	B13	B14	L18	1	✓	0.00	67.7000
19	L19	B14	B15	L19	1	✓	0.00	145.4000
20	L20	B15	B16	L20	1	✓	0.00	63.0000
21	L21	B16	B17	L21	1	✓	0.00	59.7000
22	L22	B16	B19	L22	1	✓	0.00	130.7000
23	L23	B16	B21	L23	1	✓	0.00	90.5000
24	L24	B16	B24	L24	1	✓	0.00	39.5000
25	L25	B17	B18	L25	1	✓	0.00	55.0000
26	L26	B17	B27	L26	1	✓	0.00	116.0000
27	L27	B21	B22	L27	1	✓	0.00	93.8000
28	L28	B22	B23	L28	1	✓	0.00	64.3000
29	L29	B23	B24	L29	1	✓	0.00	234.6000
30	L30	B25	B26	L30	1	✓	0.00	216.5000
31	L31	B26	B27	L31	1	✓	0.00	98.5000
32	L32	B26	B28	L32	1	✓	0.00	317.7000
33	L33	B26	B29	L33	1	✓	0.00	418.9000
34	L34	B28	B29	L34	1	✓	0.00	101.2000

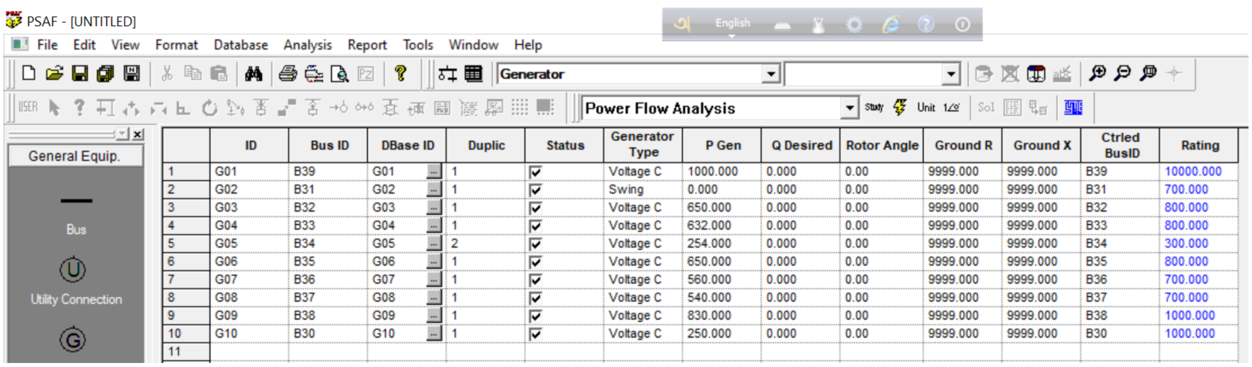
Fixed Tap Transformer Data



	ID	Bus From	Bus To	DBase ID	Duplic	Status	Tap	Set Tap on Secondary	Min Tap	Max Tap	Number of Tap	Apply Delta Grounding	R [ohm]
1	T01	B12	B11	T01	1	✓	100.00		90	110	99		0
2	T02	B12	B13	T02	1	✓	100.00		90	110	99		0
3	T03	B06	B31	T03	1	✓	100.00		90	110	99		0
4	T04	B10	B32	T04	1	✓	100.00		90	110	99		0
5	T05	B19	B33	T05	1	✓	100.00		90	110	99		0
6	T06	B20	B34	T06	2	✓	100.00		90	110	99		0
7	T07	B22	B35	T07	1	✓	100.00		90	110	99		0
8	T08	B23	B36	T08	1	✓	100.00		90	110	99		0
9	T09	B25	B37	T09	1	✓	100.00		90	110	99		0
10	T10	B01	B30	T10	1	✓	100.00		90	110	99		0
11	T11	B29	B38	T11	1	✓	100.00		90	110	99		0
12	T12	B19	B20	T12	1	✓	100.00		90	110	99		0
13													

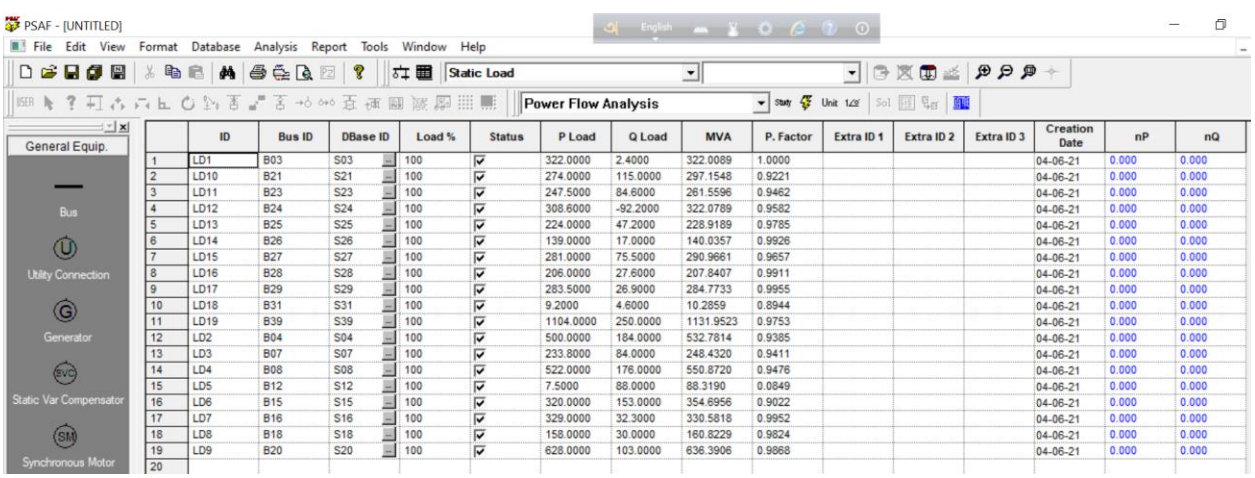
Generator Data

The generators are all 0.8 pf. The typical internal components chosen are-



	ID	Bus ID	DBase ID	Duplic	Status	Generator Type	P Gen	Q Desired	Rotor Angle	Ground R	Ground X	Ctrled BusID	Rating
1	G01	B39	G01	1	✓	Voltage C	1000.000	0.000	0.00	9999.000	9999.000	B39	10000.000
2	G02	B31	G02	1	✓	Swing	0.000	0.000	0.00	9999.000	9999.000	B31	700.000
3	G03	B32	G03	1	✓	Voltage C	650.000	0.000	0.00	9999.000	9999.000	B32	800.000
4	G04	B33	G04	1	✓	Voltage C	632.000	0.000	0.00	9999.000	9999.000	B33	800.000
5	G05	B34	G05	2	✓	Voltage C	254.000	0.000	0.00	9999.000	9999.000	B34	300.000
6	G06	B35	G06	1	✓	Voltage C	650.000	0.000	0.00	9999.000	9999.000	B35	800.000
7	G07	B36	G07	1	✓	Voltage C	560.000	0.000	0.00	9999.000	9999.000	B36	700.000
8	G08	B37	G08	1	✓	Voltage C	540.000	0.000	0.00	9999.000	9999.000	B37	700.000
9	G09	B38	G09	1	✓	Voltage C	830.000	0.000	0.00	9999.000	9999.000	B38	1000.000
10	G10	B30	G10	1	✓	Voltage C	250.000	0.000	0.00	9999.000	9999.000	B30	1000.000
11													

Static Load Data



	ID	Bus ID	DBase ID	Load %	Status	P Load	Q Load	MVA	P. Factor	Extra ID 1	Extra ID 2	Extra ID 3	Creation Date	nP	nQ
1	LD1	B03	S03	100	✓	322.0000	2.4000	322.0089	1.0000				04-06-21	0.000	0.000
2	LD10	B21	S21	100	✓	274.0000	115.0000	297.1548	0.9221				04-06-21	0.000	0.000
3	LD11	B23	S23	100	✓	247.5000	84.6000	261.5596	0.9462				04-06-21	0.000	0.000
4	LD12	B24	S24	100	✓	308.6000	-92.2000	322.0789	0.9582				04-06-21	0.000	0.000
5	LD13	B25	S25	100	✓	224.0000	47.2000	228.9189	0.9785				04-06-21	0.000	0.000
6	LD14	B26	S26	100	✓	139.0000	17.0000	140.0357	0.9926				04-06-21	0.000	0.000
7	LD15	B27	S27	100	✓	281.0000	75.5000	290.9661	0.9657				04-06-21	0.000	0.000
8	LD16	B28	S28	100	✓	206.0000	27.6000	207.8407	0.9911				04-06-21	0.000	0.000
9	LD17	B29	S29	100	✓	283.5000	26.9000	284.7733	0.9955				04-06-21	0.000	0.000
10	LD18	B31	S31	100	✓	9.2000	4.6000	10.2859	0.8944				04-06-21	0.000	0.000
11	LD19	B39	S39	100	✓	1104.0000	250.0000	1131.9523	0.9753				04-06-21	0.000	0.000
12	LD2	B04	S04	100	✓	500.0000	184.0000	532.7814	0.9385				04-06-21	0.000	0.000
13	LD3	B07	S07	100	✓	233.8000	84.0000	248.4320	0.9411				04-06-21	0.000	0.000
14	LD4	B08	S08	100	✓	522.0000	176.0000	550.8720	0.9476				04-06-21	0.000	0.000
15	LD5	B12	S12	100	✓	7.5000	88.0000	88.3190	0.0849				04-06-21	0.000	0.000
16	LD6	B15	S15	100	✓	320.0000	153.0000	354.6956	0.9022				04-06-21	0.000	0.000
17	LD7	B16	S16	100	✓	329.0000	32.3000	330.5818	0.9952				04-06-21	0.000	0.000
18	LD8	B18	S18	100	✓	158.0000	30.0000	160.8229	0.9824				04-06-21	0.000	0.000
19	LD9	B20	S20	100	✓	628.0000	103.0000	636.3906	0.9868				04-06-21	0.000	0.000
20															

For each component, the appropriate DataBase ID has been modeled, using the given parameters.

We then perform Power Flow Analysis for the selected 114 components and obtain the following results.

Summary Report

LOAD FLOW STUDY PARAMETERS	
Study :	UNTITLED
Time :	Sun Jul 25 23h47m56s 2021
Method :	Newton-Raphson
Constraints :	Applied
Flat start :	No
Tcul txfo used as fixed tap :	n\a
Block Q-flow Txfo Adjustment	n\a
Block P-flow Txfo Adjustment :	n\a
Block Switchable Shunt Adjustment :	n\a
Block DC Link Adjustment :	n\a
Base power :	100.00 [MVA]
Tolerance :	0.100 [MVA]

COMPLETE SUMMARY REPORT		
Summary Data	**Active Power**	**Reactive Power**
Total generation	**6150.399**	**1364.051**
Spinning reserve	7529.601	
Static Load	6097.100	1408.900
Shunt loads	0.000	0.000
Motor loads	0.000	0.000
Total load	**6097.100**	**1408.900**
Line / cable losses	32.780	-650.629
Transformer losses	20.520	605.780
Total losses	**53.300**	**-44.849**
Mismatches	-0.000	-0.001

Bus | Generator | Static Load | Branch | Transformer | Abnormal Report | **Summary Report**

Abnormal Report

	ID						
1							
2	BUSES OUTSIDE VOLTAGE LIMITS (100 %)						
3							
4	Bus ID	Zone	kV Base	Vmin - [pu]	Vmax - [pu]	V sol - [pu]	Ang sol - [deg]
5							
6	OVERLOADED LINES & CABLES (WITHIN 100 %)						
7	ID	Bus From	Bus To	Power Flow - [pu]	Loading Limit - [pu]	Emergency Loading Limit - [pu]	
8							
9	UNDERLOADED LINES & CABLES (WITHIN 50 %)						
10	ID	Bus From	Bus To	Power Flow - [pu]	Loading Limit - [pu]		
11	L20	B15	B16	3.547	3.585		
12	L30	B25	B26	0.564	2.390		
13	L21	B16	B17	2.578	3.585		
14	L01	B01	B02	0.807	2.390		
15	L12	B06	B11	3.573	3.585		
16	L22	B16	B19	5.118	5.378		
17	L32	B26	B28	1.433	2.390		
18	L02	B01	B39	1.792	2.390		
19	L13	B07	B08	1.727	2.390		
20	L33	B26	B29	1.914	2.390		
21	L14	B08	B09	2.041	2.390		
22	L24	B16	B24	1.534	2.390		
23	L15	B09	B39	1.708	2.390		
24	L25	B17	B18	2.186	2.390		
25	L05	B03	B04	1.432	2.390		

Bus | Generator | Static Load | Branch | Transformer | **Abnormal Report** | Summary Report

	ID						
24	L25	B17	B18	2.186	2.390		
25	L05	B03	B04	1.432	2.390		
26	L26	B17	B27	0.702	2.390		
27	L06	B03	B18	0.610	2.390		
28	L07	B04	B05	1.905	2.390		
29	L28	B22	B23	0.425	2.390		
30	L19	B14	B15	0.663	2.390		
31							
32	OVERLOADED TRANSFORMERS (WITHIN 100 %)						
33	ID	Bus From	Bus To	Power Flow - [MVA]	Loading Limit - [MVA]	Emergency Loading Limit -	
34							
35	UNDERLOADED TRANSFORMERS (WITHIN 50 %)						
36	ID	Bus From	Bus To	Power Flow -	Loading Limit -		
37	T10	B01	B30	252.990	500.000		
38	T01	B12	B11	42.456	150.000		
39	T02	B12	B13	45.924	150.000		
40	T12	B19	B20	122.909	500.000		
41	T03	B06	B31	524.052	600.000		
42							
43	GENERATORS AT REACTIVE LIMITS (WITHIN 0 %)						
44	ID	Bus From	P Gen - [MW]	Q Gen - [MVAR]	Q Min - [MVAR]	Q Max - [MVAR]	
45							
46	TRANSFORMERS AT TAP LIMITS (WITHIN 0 %)						
47	ID	Bus From	Bus To	Tap Pos - [	Min Tap - [	Max Tap - [	

Bus | Generator | Static Load | Branch | Transformer | **Abnormal Report** | Summary Report

Result: Newton-Raphson iteration and flat-start was used for this this power flow analysis, which has converged without any problem, so the data has been entered correctly. We take note that there are no overloaded lines or transformers.

Task 2

The given network consists of 10 Generator buses from bus 31-39. We performed “Fault Analysis IEC” on the same network unmodified, and observed the following faulted bus reports.

Faulted Bus Current Report

	ID	Type	Prefault kV	Angle	Fault type	Fault S [MVA]	I0 [A]	I0 [deg]	I1 [A]	I1 [deg]	I2 [A]	I2 [deg]
1	Faulted Bus ->											
2												
3	B30		16.50	0.00	LLL	n/a	0.0000	0.0000	362127.8966	-87.1808	0.0000	0.0000
4												
5	First Ring Contributions											
6												
7	G10	Generator	16.50	0.00	LLL	n/a	0.0000	0.0000	253950.1691	-87.1376	0.0000	0.0000
8	T10	Fixed-Tap Xmer	16.50	0.00	LLL	n/a	0.0000	0.0000	108177.9323	-87.2821	0.0000	0.0000
9												
10	Faulted Bus ->											
11												
12	B31		16.50	0.00	LLL	n/a	0.0000	0.0000	257189.8768	-85.5035	0.0000	0.0000
13												
14	First Ring Contributions											
15												
16	G02	Generator	16.50	0.00	LLL	n/a	0.0000	0.0000	163264.4406	-84.2894	0.0000	0.0000
17	T03	Fixed-Tap Xmer	16.50	0.00	LLL	n/a	0.0000	0.0000	94025.7444	-87.6120	0.0000	0.0000
18												
19	Faulted Bus ->											
20												
21	B32		16.50	0.00	LLL	n/a	0.0000	0.0000	300058.1458	-87.1140	0.0000	0.0000
22												
23	First Ring Contributions											
24												
25	G03	Generator	16.50	0.00	LLL	n/a	0.0000	0.0000	203160.1440	-87.1376	0.0000	0.0000
26	T04	Fixed-Tap Xmer	16.50	0.00	LLL	n/a	0.0000	0.0000	96898.0473	-87.0645	0.0000	0.0000
27												
28	Faulted Bus ->											
29												
30	B33		16.50	0.00	LLL	n/a	0.0000	0.0000	312533.2109	-86.9583	0.0000	0.0000
31												
32	First Ring Contributions											
33												
34	G04	Generator	16.50	0.00	LLL	n/a	0.0000	0.0000	203160.1440	-87.1376	0.0000	0.0000
35	T05	Fixed-Tap Xmer	16.50	0.00	LLL	n/a	0.0000	0.0000	109375.9329	-86.6254	0.0000	0.0000
36												
37	Faulted Bus ->											
38												
39	B34		16.50	0.00	LLL	n/a	0.0000	0.0000	232920.4004	-87.0516	0.0000	0.0000
40												
41	First Ring Contributions											
42												
43	G05	Generator	16.50	0.00	LLL	n/a	0.0000	0.0000	152370.0771	-87.1376	0.0000	0.0000
44	T06	Fixed-Tap Xmer	16.50	0.00	LLL	n/a	0.0000	0.0000	80550.8241	-86.8889	0.0000	0.0000
45												
46	Faulted Bus ->											
47												
48	B35		16.50	0.00	LLL	n/a	0.0000	0.0000	309026.9676	-87.2157	0.0000	0.0000
49												
50	First Ring Contributions											
51												
52	G06	Generator	16.50	0.00	LLL	n/a	0.0000	0.0000	203160.1173	-87.1376	0.0000	0.0000
53	T07	Fixed-Tap Xmer	16.50	0.00	LLL	n/a	0.0000	0.0000	105867.3842	-87.3655	0.0000	0.0000
54												

55	Faulted Bus ->											
56												
57	B36		16.50	0.00	LLL	n/a	0.0000	0.0000	259795.8568	-87.3865	0.0000	0.0000
58												
59	First Ring Contributions											
60												
61	G07	Generator	16.50	0.00	LLL	n/a	0.0000	0.0000	177765.1105	-87.1376	0.0000	0.0000
62	T08	Fixed-Tap Xmer	16.50	0.00	LLL	n/a	0.0000	0.0000	82036.0163	-87.9259	0.0000	0.0000
63												
64	Faulted Bus ->											
65												
66	B37		16.50	0.00	LLL	n/a	0.0000	0.0000	263213.6746	-85.9329	0.0000	0.0000
67												
68	First Ring Contributions											
69												
70	G08	Generator	16.50	0.00	LLL	n/a	0.0000	0.0000	177765.0839	-87.1376	0.0000	0.0000
71	T09	Fixed-Tap Xmer	16.50	0.00	LLL	n/a	0.0000	0.0000	85569.5407	-83.4298	0.0000	0.0000
72												
73	Faulted Bus ->											
74												
75	B38		16.50	0.00	LLL	n/a	0.0000	0.0000	306327.2940	-86.8201	0.0000	0.0000
76												
77	First Ring Contributions											
78												
79	G09	Generator	16.50	0.00	LLL	n/a	0.0000	0.0000	253950.1691	-87.1376	0.0000	0.0000
80	T11	Fixed-Tap Xmer	16.50	0.00	LLL	n/a	0.0000	0.0000	52399.9571	-85.2812	0.0000	0.0000
81												
82	Faulted Bus ->											
83												
84	B39		345.00	0.00	LLL	n/a	0.0000	0.0000	127495.9451	-87.1272	0.0000	0.0000
85												
86	First Ring Contributions											
87												
88	G01	Generator	345.00	0.00	LLL	n/a	0.0000	0.0000	121454.4113	-87.1376	0.0000	0.0000
89	L02	Line	345.00	0.00	LLL	n/a	0.0000	0.0000	3904.9987	-87.0590	0.0000	0.0000
90	L15	Line	345.00	0.00	LLL	n/a	0.0000	0.0000	2136.5952	-86.6601	0.0000	0.0000

Faulted bus Voltage Report

	ID	Type	Prefault kV	Angle	Fault type	V0 [pu]	V0 [deg]	V1 [pu]	V1 [deg]	V2 [pu]	V2 [deg]
1	Faulted Bus ->										
2											
3	B30		16.50	0.00	LLL	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
4											
5	First Ring Contributions										
6											
7	T10 (@ Bus : B30)	Fixed-Tap Xmer	16.50	0.00	LLL	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
8											
9	Faulted Bus ->										
10											
11	B31		16.50	0.00	LLL	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
12											
13	First Ring Contributions										
14											
15	T03 (@ Bus : B31)	Fixed-Tap Xmer	16.50	0.00	LLL	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
16											
17	Faulted Bus ->										
18											
19	B32		16.50	0.00	LLL	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
20											
21	First Ring Contributions										
22											
23	T04 (@ Bus : B32)	Fixed-Tap Xmer	16.50	0.00	LLL	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
24											
25	Faulted Bus ->										
26											
27	B33		16.50	0.00	LLL	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
28											
29	First Ring Contributions										
30											
31	T05 (@ Bus : B33)	Fixed-Tap Xmer	16.50	0.00	LLL	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
32											

33	Faulted Bus ->										
34											
35	B34		16.50	0.00	LLL	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
36											
37	First Ring Contributions										
38											
39	T06 (@ Bus : B34)	Fixed-Tap Xmer	16.50	0.00	LLL	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
40											
41	Faulted Bus ->										
42											
43	B35		16.50	0.00	LLL	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
44											
45	First Ring Contributions										
46											
47	T07 (@ Bus : B35)	Fixed-Tap Xmer	16.50	0.00	LLL	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
48											
49	Faulted Bus ->										
50											
51	B36		16.50	0.00	LLL	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
52											
53	First Ring Contributions										
54											
55	T08 (@ Bus : B36)	Fixed-Tap Xmer	16.50	0.00	LLL	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
56											
57	Faulted Bus ->										
58											
59	B37		16.50	0.00	LLL	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
60											
61	First Ring Contributions										
62											
63	T09 (@ Bus : B37)	Fixed-Tap Xmer	16.50	0.00	LLL	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
64											
65	Faulted Bus ->										
66											
67	B38		16.50	0.00	LLL	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
68											
69	First Ring Contributions										
70											
71	T11 (@ Bus : B38)	Fixed-Tap Xmer	16.50	0.00	LLL	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
72											
73	Faulted Bus ->										
74											
75	B39		345.00	0.00	LLL	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
76											
77	First Ring Contributions										
78											
79	L02 (@ Bus : B39)	Line	345.00	0.00	LLL	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
80	L15 (@ Bus : B39)	Line	345.00	0.00	LLL	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Result and Observation:

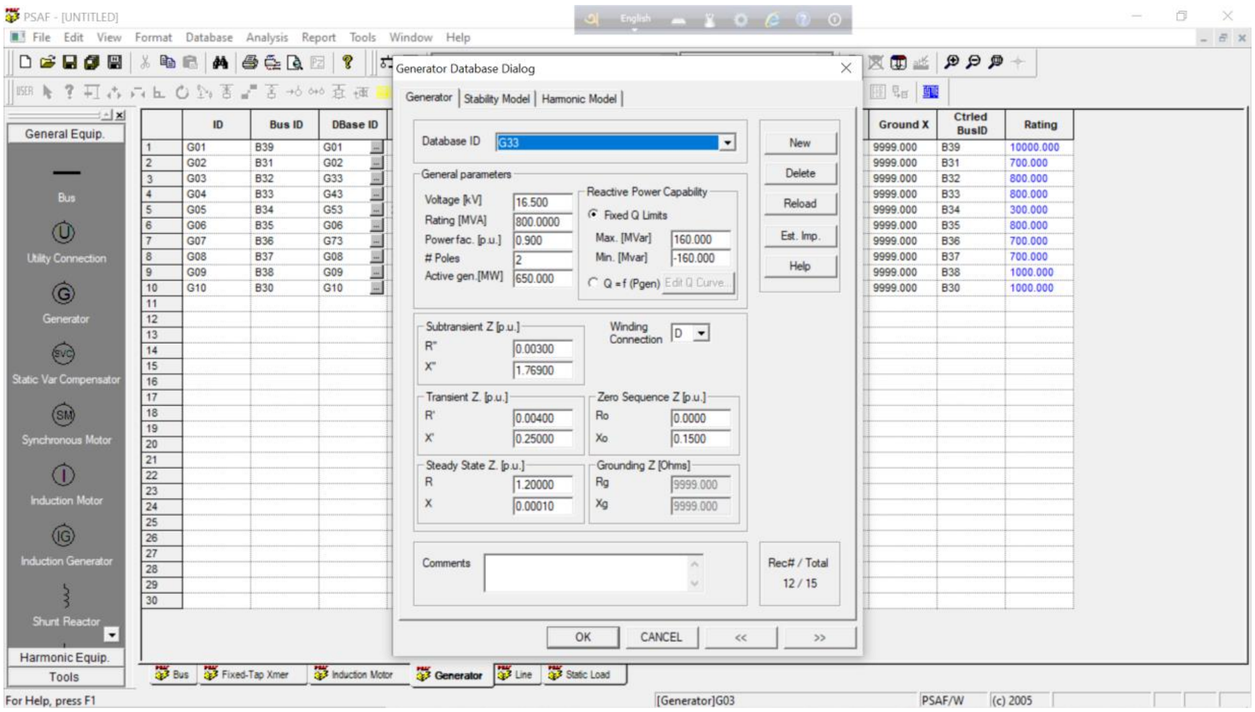
Observing this report, we determine the circuit breaker current ratings at the generator buses. It can be noted that voltages at the faulted buses are 0, as they are shorted.

Bus	Circuit breaker current rating (Ampere)
B30	362127.8966
B31	257189.8768
B32	300058.1458
B33	312533.2109
B34	232920.4004
B35	309026.9676
B36	259795.8568
B37	263213.6746
B38	306327.2940
B39	127495.9451

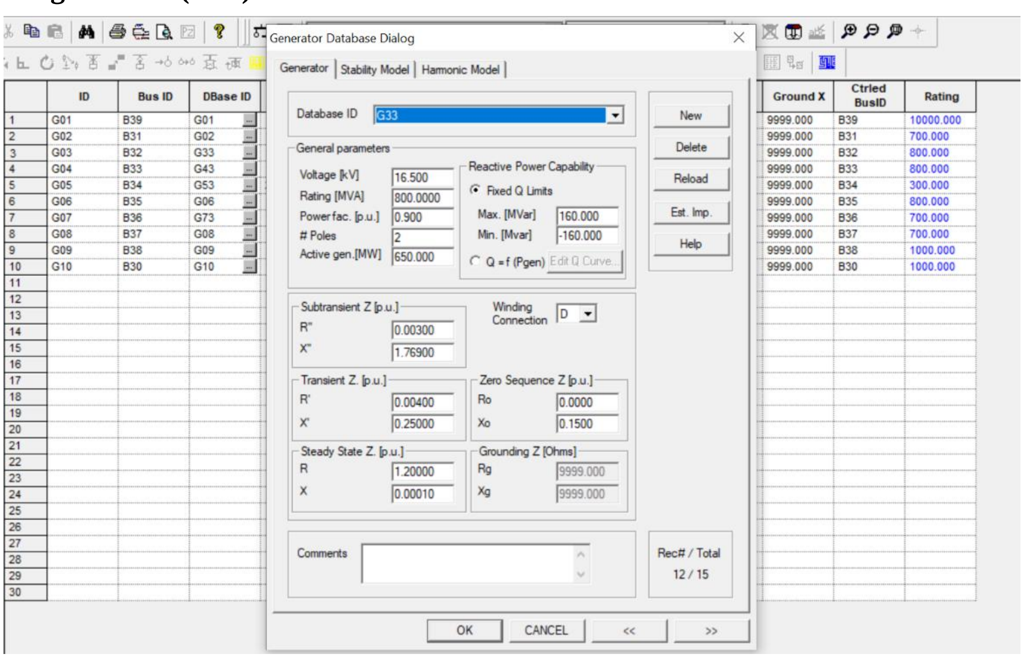
Task 3

To modify Synchronous Generators connected at bus 32,33,34,36 such that they emulate Photovoltaic Generator we made following changes. It is to be noted that only the subtransient reactance X" is increased to increase the fault current contribution and make it equal to the rated current of the generator, as required for a PV generator.

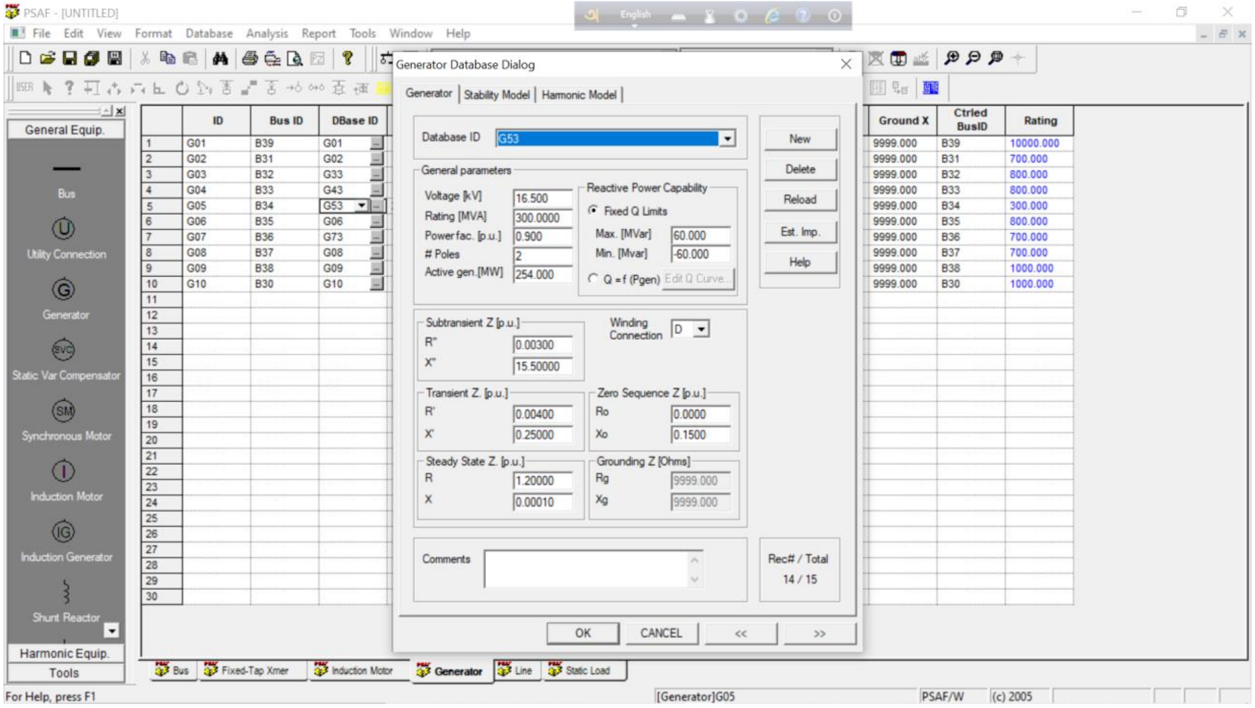
PV generator (G03) at Bus 32:



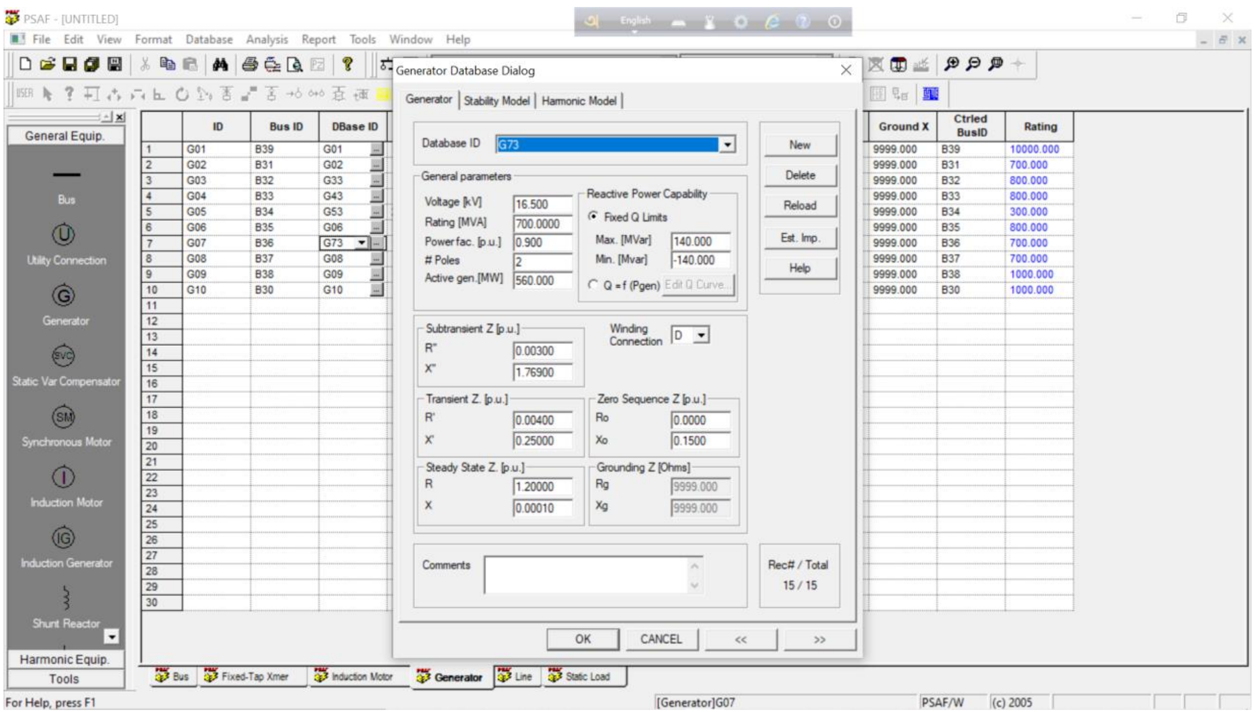
PV generator (G04) at bus33



PV generator (G05) at Bus 34



PV generator (G07) at Bus 36



Fault Analysis

Then we performed symmetrical Fault analysis at Bus 32, 33, 34, 36; and observe the following report:

	ID	Type	Prefault kV	Angle	Fault type	Fault S [MVA]	I0 [A]	I0 [deg]	I1 [A]	I1 [deg]	I2 [A]	I2 [deg]
1	Faulted Bus ->											
2												
3	B32		16.50	0.00	LLL	n/a	0.0000	0.0000	122670.4531	-87.0807	0.0000	0.0000
4												
5	First Ring Contributions											
6												
7	G03	Generator	16.50	0.00	LLL	n/a	0.0000	0.0000	27990.8173	-87.1376	0.0000	0.0000
8	T04	Fixed-Tap Xmer	16.50	0.00	LLL	n/a	0.0000	0.0000	94679.6376	-87.0639	0.0000	0.0000
9												
10	Faulted Bus ->											
11												
12	B33		16.50	0.00	LLL	n/a	0.0000	0.0000	109551.3663	-86.4659	0.0000	0.0000
13												
14	First Ring Contributions											
15												
16	G04	Generator	16.50	0.00	LLL	n/a	0.0000	0.0000	27990.8173	-87.1376	0.0000	0.0000
17	T05	Fixed-Tap Xmer	16.50	0.00	LLL	n/a	0.0000	0.0000	81563.0946	-86.2354	0.0000	0.0000
18												
19	Faulted Bus ->											
20												
21	B34		16.50	0.00	LLL	n/a	0.0000	0.0000	74306.2585	-86.6543	0.0000	0.0000
22												
23	First Ring Contributions											
24												
25	G05	Generator	16.50	0.00	LLL	n/a	0.0000	0.0000	10492.6991	-87.1375	0.0000	0.0000
26	T06	Fixed-Tap Xmer	16.50	0.00	LLL	n/a	0.0000	0.0000	63813.9894	-86.5748	0.0000	0.0000
27												
28	Faulted Bus ->											
29												
30	B36		16.50	0.00	LLL	n/a	0.0000	0.0000	103394.6959	-87.7107	0.0000	0.0000
31												
32	First Ring Contributions											
33												
34	G07	Generator	16.50	0.00	LLL	n/a	0.0000	0.0000	24491.9785	-87.1376	0.0000	0.0000
35	T08	Fixed-Tap Xmer	16.50	0.00	LLL	n/a	0.0000	0.0000	78904.3221	-87.8886	0.0000	0.0000

Result and observation

Bus	Generator	Rated Current (kA)	Fault Current Contribution (kA)	Subtransient Reactance, X''(ohm)
B32	G03	27.99	27.9908173	1.769
B34	G05	10.49	10.4926991	15.5
B33	G04	27.99	27.990173	1.769
B36	G07	24.49	24.491949	1.769

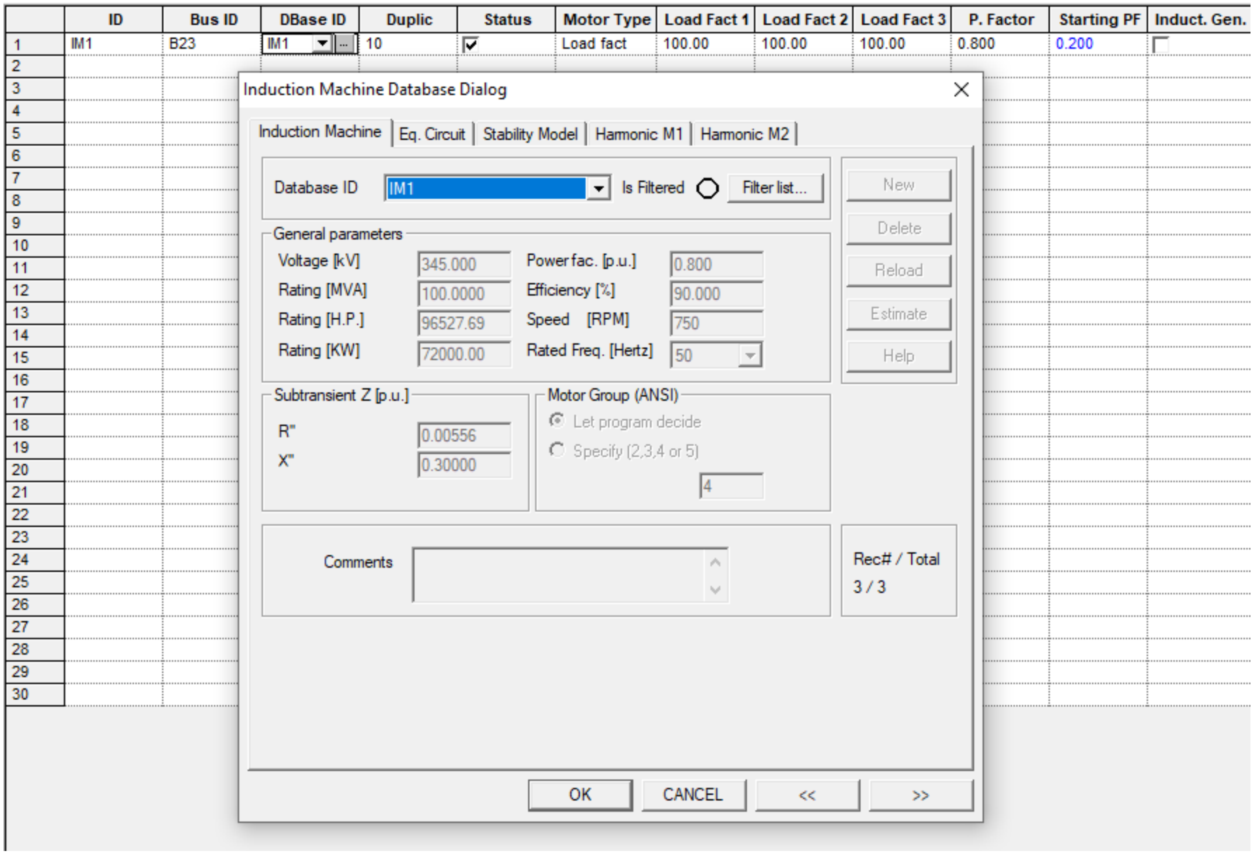
Increasing the sub transient reactance, which plays the major role at fault analysis in generators, has increased the fault current contribution as well. After several trials, the values of X” were carefully chosen to make it equal to each generator’s rated current.

Making the generators emulate PV generators has reduced the fault current in the respective buses rather significantly, as can be observed

Generator	Bus	Before modification (Ampere)	After modification (Ampere)
G03	B32	300058.1458	122670.4531
G04	B33	312533.2109	109551.3663
G05	B34	232920.4004	74306.2585
G07	B36	259795.8568	103394.6959

Task 4

We added an induction motor to the original network, as instructed. Duplicity = 10 means there are actually 10 induction motors, which models a working power plant that drastically affects network pf.



Load Flow Analysis

Then we performed Load Flow Analysis and observed the reports.

Summary Report

LOAD FLOW STUDY PARAMETERS

Study :	UNTITLED
Time :	Sun Jul 25 23h52m54s 2021
Method :	Fast Decoupled
Constraints :	Applied
Flat start :	No
Tcul txfo used as fixed tap :	n\a
Block Q-flow Txfo Adjustment	n\a
Block P-flow Txfo Adjustment :	n\a
Block Switchable Shunt Adjustment :	n\a
Block DC Link Adjustment :	n\a
Base power :	100.00 [MVA]
Tolerance :	0.100 [MVA]

COMPLETE SUMMARY REPORT

Summary Data	Active Power	Reactive Power
Total generation	**6977.910**	**2780.244**
Spinning reserve	6702.090	
Static Load	6097.100	1408.900
Shunt loads	0.000	0.000
Motor loads	800.000	600.000
Total load	**6897.100**	**2008.900**
Line / cable losses	45.335	-412.063
Transformer losses	35.468	1183.437
Total losses	**80.803**	**771.374**
Mismatches	0.008	-0.030

Abnormal Report

	ID						
1							
2	***BUSES OUTSIDE VOLTAGE LIMITS (100 %)***						
3							
4	**Bus ID**	**Zone**	**kV Base**	**Vmin - [kv]**	**Vmax - [kv]**	**V sol - [kv]**	**Ang sol - [deg]**
5	B12	0	138.00	124.20	151.80	123.36	-22.7
6	B23	0	345.00	310.50	379.50	304.12	-37.5
7							
8	***OVERLOADED LINES & CABLES (WITHIN 100 %)***						
9	**ID**	**Bus From**	**Bus To**	**Power Flow - [A]**	**Loading Limit - [A]**	**Emergency Loading Limit - [A]**	
10	L11	B06	B07	894.5	800.0	850.0	
11	L17	B10	B13	1076.1	800.0	850.0	
12	L07	B04	B05	1087.0	800.0	850.0	
13	L18	B13	B14	1108.2	800.0	850.0	
14	L28	B22	B23	1034.7	800.0	850.0	
15	L19	B14	B15	841.2	800.0	850.0	
16	L09	B05	B06	1632.6	1200.0	1800.0	
17							
18	***UNDERLOADED LINES & CABLES (WITHIN 50 %)***						
19	**ID**	**Bus From**	**Bus To**	**Power Flow - [A]**	**Loading Limit - [A]**		
20	L20	B15	B16	434.6	600.0		
21	L30	B25	B26	240.8	400.0		
22	L21	B16	B17	315.4	600.0		
23	L01	B01	B02	305.0	400.0		
24	L12	B06	B11	186.3	600.0		
25	L32	B26	B28	261.4	400.0		
26	L02	B01	B39	147.8	400.0		
27	L23	B16	B21	189.8	400.0		
28	L33	B26	B29	340.4	400.0		
29	L04	B02	B25	304.8	400.0		
30	L15	B09	B39	373.2	400.0		
31	L25	B17	B18	136.7	400.0		
32	L16	B10	B11	253.0	600.0		
33	L26	B17	B27	209.7	400.0		
34	L27	B21	B22	348.9	600.0		
35	L08	B04	B14	276.6	400.0		
36	L29	B23	B24	225.3	400.0		
37							

38	***OVERLOADED TRANSFORMERS (WITHIN 100 %)***						
39	ID	Bus From	Bus To	Power Flow - [MVA]	Loading Limit - [MVA]	Emergency Loading Limit - [MVA]	
40	T03	B06	B31	1335.0	1200.0	1250.0	
41							
42	***UNDERLOADED TRANSFORMERS (WITHIN 50 %)***						
43	ID	Bus From	Bus To	Power Flow - [MVA]	Loading Limit - [MVA]		
44	T10	B01	B30	257.9	500.0		
45	T01	B12	B11	52.3	150.0		
46	T02	B12	B13	49.4	150.0		
47	T12	B19	B20	133.1	500.0		
48							
49	***GENERATORS AT REACTIVE LIMITS (WITHIN 0 %)***						
50	ID	Bus From	P Gen - [MW]	Q Gen - [MVAR]	Q Min - [MVAR]	Q Max - [MVAR]	
51	G06	B35	650.00	448.01	-192.00	448.00	
52	G07	B36	560.00	392.07	-168.00	392.00	
53							
54	***TRANSFORMERS AT TAP LIMITS (WITHIN 0 %)***						
55	ID	Bus From	Bus To	Tap Pos - [kv]	Min Tap - [kv]	Max Tap - [kv]	

Generator report

	ID	Bus ID	DBase ID	Type	Rated S [MVA]	kV Nominal	Generator Type	P [MW]	Q [MVAR]	S [MVA]	P. Factor [%]	I [pu]	Q max. [MVAR]	Q min. [MVAR]	Ctrled BusID	Ctrld Bus/V [pu]
1	G10	B30	G10	Generator	1000.00	16.50	PV	250.00	76.11	261.33	95.7	2.495	560.00	-240.00	B30	1.048
2	G01	B39	G01	Generator	10000.00	345.00	PV	1000.00	300.59	1044.20	95.8	10.138	5600.00	-2400.00	B39	1.030
3	G02	B31	G02	Generator	700.00	16.50	SW	1357.91	522.78	1455.06	93.3	14.817	392.00	-168.00	B31	0.982
4	G03	B32	G03	Generator	800.00	16.50	PV	650.00	329.87	728.91	89.2	7.415	448.00	-192.00	B32	0.983
5	G04	B33	G04	Generator	800.00	16.50	PV	632.00	203.45	663.94	95.2	6.658	448.00	-192.00	B33	0.997
6	G05	B34	G05	Generator	600.00	16.50	PV	508.00	210.03	549.71	92.4	5.430	336.00	-144.00	B34	1.012
7	G06	B35	G06	Generator	800.00	16.50	PV	650.00	448.09	789.49	82.3	8.036	448.00	-192.00	B35	0.982
8	G07	B36	G07	Generator	700.00	16.50	PV	560.00	392.06	683.60	81.9	6.977	392.00	-168.00	B36	0.980
9	G08	B37	G08	Generator	700.00	16.50	PV	540.00	166.82	565.18	95.5	5.499	392.00	-168.00	B37	1.028
10	G09	B38	G09	Generator	1000.00	16.50	PV	830.00	130.31	840.17	98.8	8.185	560.00	-240.00	B38	1.026

Line report

	ID	Bus From	Bus To	DBase ID	Type	kV Nominal	Length	P [MW]	Q [MVAR]	S [MVA]	P. Factor [%]	I [pu]	I angle [deg]	P losses [MW]	Q losses [MVAR]	Ampacity (Norm.) [pu]	Loading %	Ampacity (Emer.) [pu]	Loading(Emer) %
1	L10	B05	B08	L10	Line	345.00	75.1000	294.83	-1.57	294.83	100.0	3.258	-23.3	0.85	-0.16	4.780	68.2	5.079	64.1
2	L20	B15	B16	L20	Line	345.00	63.0000	130.90	-195.16	235.00	55.7	2.597	21.6	0.58	-8.26	7.171	36.2	10.756	24.1
3	L30	B25	B26	L30	Line	345.00	216.5000	143.05	4.27	143.11	100.0	1.439	-30.5	0.69	-43.07	4.780	30.1	5.079	28.3
4	L11	B06	B07	L11	Line	345.00	61.7000	483.09	43.01	485.00	99.6	5.345	-27.1	1.72	17.10	4.780	111.8	5.079	105.2
5	L21	B16	B17	L21	Line	345.00	59.7000	-126.54	-119.36	173.95	-72.7	1.884	101.2	0.24	-8.57	7.171	26.3	10.756	17.5
6	L31	B26	B27	L31	Line	345.00	98.5000	333.76	153.45	367.34	90.9	3.744	-56.1	2.02	-1.24	4.780	78.3	5.079	73.7
7	L01	B01	B02	L1	Line	345.00	275.5000	163.18	94.19	188.42	86.6	1.823	-55.9	1.44	-53.84	4.780	38.1	5.079	35.9
8	L12	B06	B11	L12	Line	345.00	55.0000	-32.90	-95.52	101.03	-32.6	1.113	87.0	0.08	-10.63	7.171	15.5	10.756	10.4
9	L22	B16	B19	L22	Line	345.00	130.7000	-501.00	-156.92	525.00	-95.4	5.686	127.1	5.10	34.97	10.756	52.9	16.134	35.2
10	L32	B26	B28	L32	Line	345.00	317.7000	-141.03	-60.00	153.26	-92.0	1.562	125.5	0.91	-66.57	4.780	32.7	5.079	30.8
11	L02	B01	B39	L2	Line	345.00	167.6000	86.44	-29.34	91.29	94.7	0.883	-7.1	0.07	-82.96	4.780	18.5	5.079	17.4
12	L13	B07	B08	L13	Line	345.00	30.8000	247.57	-58.09	254.30	97.4	2.824	-11.9	0.32	-2.69	4.780	59.1	5.079	55.6
13	L23	B16	B21	L23	Line	345.00	90.5000	87.73	57.10	104.68	83.8	1.134	-68.5	0.12	-19.52	4.780	23.7	5.079	22.3
14	L33	B26	B29	L33	Line	345.00	418.9000	-189.37	-63.10	199.61	-94.9	2.034	130.1	2.13	-78.39	4.780	42.6	5.079	40.1
15	L03	B02	B03	L3	Line	345.00	101.2000	330.61	204.63	388.82	85.0	3.976	-61.2	2.13	1.00	4.780	83.2	5.079	78.3
16	L14	B08	B09	L14	Line	345.00	243.3000	19.24	-232.82	233.61	8.2	2.589	59.3	1.34	-12.93	4.780	54.2	5.079	51.0
17	L24	B16	B24	L24	Line	345.00	39.5000	341.14	-0.03	341.14	100.0	3.695	-35.5	0.41	2.26	4.780	77.3	5.079	72.7
18	L34	B28	B29	L34	Line	345.00	101.2000	-347.94	-21.03	348.57	-99.8	3.484	149.0	1.69	-6.83	4.780	72.9	5.079	68.6
19	L04	B02	B25	L4	Line	345.00	57.6000	-168.88	-56.60	178.11	-94.8	1.821	132.0	2.27	-11.41	4.780	38.1	5.079	35.9
20	L15	B09	B39	L15	Line	345.00	167.6000	17.90	-219.89	220.62	8.1	2.230	58.7	0.27	-115.68	4.780	46.6	5.079	43.9
21	L25	B17	B18	L25	Line	345.00	55.0000	-76.20	-5.10	76.37	-99.8	0.817	141.4	0.05	-11.00	4.780	17.1	5.079	16.1
22	L05	B03	B04	L5	Line	345.00	142.8000	-228.45	187.60	295.60	-77.3	3.141	-173.0	1.34	3.12	4.780	65.7	5.079	61.8
23	L16	B10	B11	L16	Line	345.00	28.8000	62.07	124.80	139.38	44.5	1.512	-85.3	0.10	-5.13	7.171	21.1	10.756	14.1
24	L26	B17	B27	L26	Line	345.00	116.0000	-50.58	-105.69	117.17	-43.2	1.253	80.8	0.16	-26.50	4.780	26.2	5.079	24.7
25	L06	B03	B18	L6	Line	345.00	89.1000	234.94	13.64	235.33	99.8	2.500	-35.7	0.69	-10.46	4.780	52.3	5.079	49.2
26	L17	B10	B13	L17	Line	345.00	28.8000	585.18	95.09	592.85	98.7	6.430	-31.0	1.66	11.66	4.780	134.5	5.079	126.6
27	L27	B21	B22	L27	Line	345.00	93.8000	-186.36	-38.38	190.27	-97.9	2.085	132.1	0.34	-15.55	7.171	29.1	10.756	19.4
28	L07	B04	B05	L7	Line	345.00	85.8000	-584.48	33.34	585.43	-99.8	6.495	154.4	3.38	43.12	4.780	135.9	5.079	127.9
29	L18	B13	B14	L18	Line	345.00	67.7000	604.91	37.66	606.08	99.8	6.622	-27.0	3.95	30.06	4.780	138.5	5.079	130.4
30	L28	B22	B23	L28	Line	345.00	64.3000	460.40	332.89	568.14	81.0	6.182	-70.3	2.33	22.32	4.780	129.3	5.079	121.7
31	L08	B04	B14	L8	Line	345.00	86.5000	-145.30	-32.87	148.97	-97.5	1.653	138.4	0.22	-7.83	4.780	34.6	5.079	32.5
32	L19	B14	B15	L19	Line	345.00	145.4000	455.43	-17.45	455.77	99.9	5.026	-25.4	4.54	24.72	4.780	105.1	5.079	99.0
33	L29	B23	B24	L29	Line	345.00	234.6000	-31.83	-114.31	118.66	-26.8	1.346	68.1	0.31	-24.40	4.780	28.2	5.079	26.5
34	L09	B05	B06	L9	Line	345.00	17.4000	-882.68	-8.20	882.72	-100.0	9.755	155.9	1.90	21.18	7.171	136.0	10.756	90.7

Transformer report

	TXFO ID	Bus From	Bus To	DBase ID	Type	Rated S [MVA]	kV Nominal Primary	kV Nominal Secondary	P [MW]	Q [MVAR]	S [MVA]	P. Factor [%]	I [pu]	Iangle [deg]	P losses [MW]	Q losses [MVAR]	Capacity (Norm.) [MVA]	Loading [%] Capacity	Capacity (Emer.) [MVA]
1																			
2																			
3	T10	B01	B30	T10	Fixed-Tap Xmer	1000.00	345.00	16.50	-249.63	-64.85	257.91	-96.8	2.495	139.6	0.37	11.27	1000.00	25.8	1500.00
4	T01	B12	B11	T01	Fixed-Tap Xmer	300.00	138.00	345.00	-28.94	-43.55	52.29	-55.4	0.585	100.9	0.05	1.49	300.00	17.4	450.00
5	T11	B29	B38	T11	Fixed-Tap Xmer	1000.00	345.00	16.50	-824.64	-25.80	825.04	-100.0	8.185	153.6	5.36	104.50	1000.00	82.5	1500.00
6	T02	B12	B13	T02	Fixed-Tap Xmer	300.00	138.00	345.00	21.44	-44.45	49.35	43.5	0.552	41.5	0.05	1.33	300.00	16.5	450.00
7	T12	B19	B20	T12	Fixed-Tap Xmer	1000.00	345.00	230.00	122.78	-51.36	133.09	92.3	1.375	-6.7	0.13	2.61	1000.00	13.3	1500.00
8	T03	B06	B31	T03	Fixed-Tap Xmer	700.00	345.00	16.50	-1334.79	23.13	1334.99	-100.0	14.713	159.0	13.92	541.32	1200.00	111.2	1250.00
9	T04	B10	B32	T04	Fixed-Tap Xmer	800.00	345.00	16.50	-647.25	-219.89	683.58	-94.7	7.414	139.5	2.75	109.98	800.00	85.4	1200.00
10	T05	B19	B33	T05	Fixed-Tap Xmer	800.00	345.00	16.50	-628.90	-140.52	644.40	-97.6	6.658	138.1	3.10	62.92	810.00	79.6	1200.00
11	T06	B20	B34	T06	Fixed-Tap Xmer	600.00	230.00	16.50	-505.35	-156.97	529.16	-95.5	5.430	132.3	2.65	53.06	600.00	88.2	900.00
12	T07	B22	B35	T07	Fixed-Tap Xmer	800.00	345.00	16.50	-647.11	-355.72	738.44	-87.6	8.036	116.7	2.83	92.37	800.00	92.3	1200.00
13	T08	B23	B36	T08	Fixed-Tap Xmer	700.00	345.00	16.50	-557.50	-259.70	615.02	-90.6	6.976	117.6	2.43	132.36	700.00	87.9	1050.00
14	T09	B25	B37	T09	Fixed-Tap Xmer	700.00	345.00	16.50	-538.18	-96.65	546.79	-98.4	5.499	141.0	1.81	70.17	700.00	78.1	1050.00

Bus Report

	ID	Zone	kV Base	V sol [pu]	Ang sol [deg]	Vmin [pu]	Vmax [pu]	P Gen [MW]	Q Gen [MVAR]	P Load [MW]	Q Load [MVAR]	P motor [MW]	Q motor [MVAR]	P shunt [MW]	Q shunt [MVAR]
1	B01	0	345.00	1.034	-25.9	0.900	1.100	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	B02	0	345.00	0.978	-29.4	0.900	1.100	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	B03	0	345.00	0.941	-32.4	0.900	1.100	0.00	0.00	322.00	2.40	0.00	0.00	0.00	0.00
4	B04	0	345.00	0.901	-28.9	0.900	1.100	0.00	0.00	500.00	184.00	0.00	0.00	0.00	0.00
5	B05	0	345.00	0.905	-23.6	0.900	1.100	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	B06	0	345.00	0.907	-22.0	0.900	1.100	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	B07	0	345.00	0.901	-25.1	0.900	1.100	0.00	0.00	233.80	84.00	0.00	0.00	0.00	0.00
8	B08	0	345.00	0.902	-25.9	0.900	1.100	0.00	0.00	522.00	176.00	0.00	0.00	0.00	0.00
9	B09	0	345.00	0.989	-26.7	0.900	1.100	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	B10	0	345.00	0.922	-21.7	0.900	1.100	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	B11	0	345.00	0.916	-21.9	0.900	1.100	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12	B12	0	138.00	0.894	-22.7	0.900	1.100	0.00	0.00	7.50	88.00	0.00	0.00	0.00	0.00
13	B13	0	345.00	0.915	-23.4	0.900	1.100	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14	B14	0	345.00	0.907	-27.6	0.900	1.100	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15	B15	0	345.00	0.905	-34.5	0.900	1.100	0.00	0.00	320.00	153.00	0.00	0.00	0.00	0.00
16	B16	0	345.00	0.923	-35.5	0.900	1.100	0.00	0.00	329.00	32.30	0.00	0.00	0.00	0.00
17	B17	0	345.00	0.935	-34.8	0.900	1.100	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18	B18	0	345.00	0.936	-34.4	0.900	1.100	0.00	0.00	158.00	30.00	0.00	0.00	0.00	0.00
19	B19	0	345.00	0.968	-29.4	0.900	1.100	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	B20	0	230.00	0.974	-30.4	0.900	1.100	0.00	0.00	628.00	103.00	0.00	0.00	0.00	0.00
21	B21	0	345.00	0.913	-36.2	0.900	1.100	0.00	0.00	274.00	115.00	0.00	0.00	0.00	0.00
22	B22	0	345.00	0.919	-34.5	0.900	1.100	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
23	B23	0	345.00	0.882	-37.5	0.900	1.100	0.00	0.00	247.50	84.60	800.00	600.00	0.00	0.00
24	B24	0	345.00	0.922	-36.8	0.900	1.100	0.00	0.00	308.60	-92.20	0.00	0.00	0.00	0.00
25	B25	0	345.00	0.994	-28.8	0.900	1.100	0.00	0.00	224.00	47.20	0.00	0.00	0.00	0.00
26	B26	0	345.00	0.981	-31.4	0.900	1.100	0.00	0.00	139.00	17.00	0.00	0.00	0.00	0.00
27	B27	0	345.00	0.953	-34.3	0.900	1.100	0.00	0.00	281.00	75.50	0.00	0.00	0.00	0.00
28	B28	0	345.00	1.000	-27.6	0.900	1.100	0.00	0.00	206.00	27.60	0.00	0.00	0.00	0.00
29	B29	0	345.00	1.008	-24.6	0.900	1.100	0.00	0.00	283.50	26.90	0.00	0.00	0.00	0.00
30	B30	0	16.50	1.048	-23.5	0.900	1.100	250.00	76.12	0.00	0.00	0.00	0.00	0.00	0.00
31	B31	0	16.50	0.982	0.0	0.900	1.100	1357.91	522.81	9.20	4.60	0.00	0.00	0.00	0.00
32	B32	0	16.50	0.983	-13.6	0.900	1.100	650.00	329.91	0.00	0.00	0.00	0.00	0.00	0.00
33	B33	0	16.50	0.997	-24.1	0.900	1.100	632.00	203.50	0.00	0.00	0.00	0.00	0.00	0.00
34	B34	0	16.50	1.012	-25.2	0.900	1.100	508.00	210.06	0.00	0.00	0.00	0.00	0.00	0.00
35	B35	0	16.50	0.982	-28.7	0.900	1.100	650.00	448.01	0.00	0.00	0.00	0.00	0.00	0.00
36	B36	0	16.50	0.980	-27.4	0.900	1.100	560.00	392.07	0.00	0.00	0.00	0.00	0.00	0.00
37	B37	0	16.50	1.028	-21.8	0.900	1.100	540.00	166.85	0.00	0.00	0.00	0.00	0.00	0.00
38	B38	0	16.50	1.026	-17.5	0.900	1.100	830.00	130.33	0.00	0.00	0.00	0.00	0.00	0.00
39	B39	0	345.00	1.030	-27.0	0.900	1.100	1000.00	300.60	1104.00	250.00	0.00	0.00	0.00	0.00

Induction Motor Report

	ID	Bus ID	DBase ID	Type	V sol [kv]	S [MVA]	P. Factor [%]	I [A]
1	IM1	B23	IM1	Induction Motor	304.12	1000.00	80.0	1898.4

Result and Observation

We can observe significant overload in several lines and Transformer 3 here. In Line 7, 11, 17, 18, 18, overload current is greater than the emergency limit, and in line 9 and 19, the overload current is below emergency but still above maximum limit. Transformer 03, which is connected to the swing generator, is also overloaded above emergency limit.

The reason is the drastic increase in load. The induction motor plant is drawing a significant amount of reactive power from bus 23. There are 10 in total, each feeding 60 MVA reactive power (thus, 600 MVA in total). This decreases the power factor of the total system significantly.

It is to be noted that the amount of active load has increased as well. But the overall pf of the power plant is 0.8, lower than the previous system pf. Thus this large load plays a notable role in pulling down the overall system pf.

We can show this quantitatively by comparing the result with that of task 1.

In task 1, active generation = 6150.399 MW; Reactive Generation = 1364.051 MVAR.

So, pf = $\cos(\tan^{-1}(1364.051/6150.399))$ = **0.97627**

In task 4, active generation = 6977.910 MW; Reactive Generation = 2780.244 MVAR.

So, pf = $\cos(\tan^{-1}(2780.244/6977.910))$ = **0.9289**

Thus, the overall apparent power (S) increases by a lot, while power factor goes down. This increases line current, and loss is increased as well (from **53.3 – 44.849i MVA**R to **80.803 + 771.374i** MVAR), most of which is reactive.

The power imbalance is supplied by the swing generator, and we can see from report that it is supplying power much higher than its rated value. This causes excessive power flow in the transformer immediately attached to it (T03), which causes the overload.

The Bus voltage at induction Motor plant is reduced as well, due to increased current, it is 304.12V (0.88pu) in place of rated 345 V.

Task 5

In this task we tried to fix overload problems caused by induction motors. To compensate for the reactive power, we added some static VAR compensators, which are capacitors that supply reactive power locally to decrease pressure on generation and thus reduce line current. We also added SVC to the two sides of some overloaded lines, and also with some loads that were feeding significant reactive power (Bus 04, for example).

But the active power of the system has significantly risen as well, which causes an imbalance between the power rating and the power demand. This was supplied by the Swing generator, and was causing a overflow in the lines. A way to solve this is to distribute this demand among the voltage-controlled generators, so that the extra power is supplied locally and is distributed throughout the whole network rather than putting pressure on the swing. This scheme is known as swing distribution. After several trials and errors, we chose the optimum values for both the SVCs and the updated active power rating of the generators, that finally got rid of the overload.

Adding Static VAR Compensator

	ID	Bus ID	DBase ID	Duplic	Status	Q	Ctrl'd Bus	L	Q Max	Q Min
1	C04	B04	SC4 ...	1	☑	180.000	B04	1267.11804	300.000	1.000
2	C10	B10	SC10 ...	1	☑	200.000	B10	1521.55945	250.000	1.000
3	C12	B12	S12 ...	1	☑	80.000	B12	2542.74023	150.000	1.000
4	C13	B13	SC13 ...	1	☑	200.000	B13	1521.559	250.000	1.000
5	C14	B14	SC14 ...	1	☑	200.000	B14	3.480	250.000	1.000
6	C15	B15	SC15 ...	1	☑	200.000	B15	1521.559	250.000	1.000
7	C23	B23	SC23 ...	1	☑	600.000	B23	1515.473	800.000	550.000

Increasing active power generation of generator:

	ID	Bus ID	DBase ID	Duplic	Status	Generator Type	P Gen	Q Desired	Rotor Angle	Ground R	Ground X	Ctrled BusID	Rating
1	G01	B39	G01_5 ...	1	☑	Voltage C	1000.000	0.000	0.00	9999.000	9999.000	B39	10000.000
2	G02	B31	G02 ...	1	☑	Swing	0.000	0.000	0.00	9999.000	9999.000	B31	700.000
3	G03	B32	G03_5 ...	1	☑	Voltage C	750.000	0.000	0.00	9999.000	9999.000	B32	800.000
4	G04	B33	G04_5 ...	1	☑	Voltage C	750.000	0.000	0.00	9999.000	9999.000	B33	800.000
5	G05	B34	G05_5 ...	2	☑	Voltage C	270.000	0.000	0.00	9999.000	9999.000	B34	300.000
6	G06	B35	G06_5 ...	1	☑	Voltage C	700.000	0.000	0.00	9999.000	9999.000	B35	800.000
7	G07	B36	G07_5 ...	1	☑	Voltage C	600.000	0.000	0.00	9999.000	9999.000	B36	700.000
8	G08	B37	G08_5 ...	1	☑	Voltage C	540.000	0.000	0.00	9999.000	9999.000	B37	700.000
9	G09	B38	G09_5 ...	1	☑	Voltage C	900.000	0.000	0.00	9999.000	9999.000	B38	1000.000
10	G10	B30	G10_5 ...	1	☑	Voltage C	500.000	0.000	0.00	9999.000	9999.000	B30	1000.000
11													

Power Flow Analysis

Now we again solve the network and observe the report

Summary Report

LOAD FLOW STUDY PARAMETERS	
Study :	UNTITLED
Time :	Mon Jul 26 10h58m53s 2021
Method :	Fast Decoupled
Constraints :	Applied
Flat start :	No
Tcul txfo used as fixed tap :	n\a
Block Q-flow Txfo Adjustment	n\a
Block P-flow Txfo Adjustment :	n\a
Block Switchable Shunt Adjustment :	n\a
Block DC Link Adjustment :	n\a
Base power :	100.00 [MVA]
Tolerance :	0.100 [MVA]

COMPLETE SUMMARY REPORT		
Summary Data	**Active Power**	**Reactive Power**
Total generation	**6958.375**	**2118.694**
Spinning reserve	6721.625	
Static Load	6097.100	1408.900
Shunt loads	0.000	0.000
Motor loads	800.000	600.000
Total load	**6897.100**	**2008.900**
Line / cable losses	35.494	-652.228
Transformer losses	25.779	761.966
Total losses	**61.273**	**109.738**
Mismatches	0.002	0.056

Abnormal report

	ID						
1							
2	***BUSES OUTSIDE VOLTAGE LIMITS (100 %)***						
3							
4	Bus ID	Zone	kV Base	Vmin - [pu]	Vmax - [pu]	V sol - [pu]	Ang sol - [deg]
5							
6	***OVERLOADED LINES & CABLES (WITHIN 100 %)***						
7	ID	Bus From	Bus To	Power Flow - [pu]	Loading Limit - [pu]	Emergency Loading Limit - [pu]	
8							
9	***UNDERLOADED LINES & CABLES (WITHIN 50 %)***						
10	ID	Bus From	Bus To	Power Flow - [pu]	Loading Limit - [pu]		
11	L20	B15	B16	0.683	3.585		
12	L30	B25	B26	1.120	2.390		
13	L21	B16	B17	0.745	3.585		
14	L12	B06	B11	2.942	3.585		
15	L32	B26	B28	1.722	2.390		
16	L13	B07	B08	1.459	2.390		
17	L23	B16	B21	0.482	2.390		
18	L33	B26	B29	2.206	2.390		
19	L14	B08	B09	1.917	2.390		
20	L04	B02	B25	2.005	2.390		
21	L15	B09	B39	1.688	2.390		
22	L25	B17	B18	0.174	2.390		
23	L05	B03	B04	0.264	2.390		
24	L16	B10	B11	2.971	3.585		
25	L26	B17	B27	0.893	2.390		
26	L06	B03	B18	1.402	2.390		
27	L27	B21	B22	2.664	3.585		
28	L08	B04	B14	1.959	2.390		
29	L29	B23	B24	0.094	2.390		
30							

31	OVERLOADED TRANSFORMERS (WITHIN 100 %)						
32	ID	Bus From	Bus To	Power Flow - [MVA]	Loading Limit - [MVA]	Emergency Loading Limit - [MVA]	
33							
34	UNDERLOADED TRANSFORMERS (WITHIN 50 %)						
35	ID	Bus From	Bus To	Power Flow - [MVA]	Loading Limit - [MVA]		
36	T10	B01	B30	498.709	500.000		
37	T01	B12	B11	15.787	150.000		
38	T02	B12	B13	5.342	150.000		
39	T12	B19	B20	94.825	500.000		
40							
41	GENERATORS AT REACTIVE LIMITS (WITHIN 0 %)						
42	ID	Bus From	P Gen - [MW]	Q Gen - [MVAR]	Q Min - [MVAR]	Q Max - [MVAR]	
43							
44	TRANSFORMERS AT TAP LIMITS (WITHIN 0 %)						
45	ID	Bus From	Bus To	Tap Pos - [%]	Min Tap - [%]	Max Tap - [%]	

Generator Report

	ID	Bus ID	DBase ID	Type	Rated S [MVA]	kV Nominal	Generator Type	P [MW]	Q [MVAR]	S [MVA]	P. Factor [%]	I [pu]	Q max. [MVAR]	Q min. [MVAR]	Ctrled BusID	Ctrld Bus/V [pu]
1	G10	B30	G10_5	Generator	1000.00	16.50	PV	500.00	51.06	502.60	99.5	4.798	560.00	-240.00	B30	1.048
2	G01	B39	G01_5	Generator	10000.00	345.00	PV	1000.00	160.15	1012.74	98.7	9.832	5600.00	-2400.00	B39	1.030
3	G02	B31	G02	Generator	700.00	16.50	SW	678.37	30.99	679.08	99.9	6.915	392.00	-168.00	B31	0.982
4	G03	B32	G03_5	Generator	800.00	16.50	PV	750.00	-43.95	751.29	99.8	7.642	448.00	-192.00	B32	0.983
5	G04	B33	G04_5	Generator	800.00	16.50	PV	750.00	31.92	750.68	99.9	7.528	448.00	-192.00	B33	0.997
6	G05	B34	G05_5	Generator	600.00	16.50	PV	540.00	131.06	555.68	97.2	5.489	336.00	-144.00	B34	1.012
7	G06	B35	G06_5	Generator	800.00	16.50	PV	700.00	198.71	727.66	96.2	6.939	448.00	-192.00	B35	1.049
8	G07	B36	G07_5	Generator	700.00	16.50	PV	600.00	211.95	636.34	94.3	5.983	392.00	-168.00	B36	1.064
9	G08	B37	G08_5	Generator	700.00	16.50	PV	540.00	36.50	541.23	99.8	5.266	392.00	-168.00	B37	1.028
10	G09	B38	G09_5	Generator	1000.00	16.50	PV	900.00	63.84	902.26	99.7	8.790	560.00	-240.00	B38	1.026
11	C10	B10	SC10	Static Var Compensator	250.00	345.00	PV	0.00	195.80	195.80	0.0	1.958	250.00	1.00	B10	1.000
12	C12	B12	S12	Static Var Compensator	150.00	345.00	PV	0.00	95.87	95.87	0.0	0.959	150.00	1.00	B12	0.999
13	C13	B13	SC13	Static Var Compensator	250.00	345.00	PV	0.00	5.32	5.32	0.0	0.053	250.00	1.00	B13	1.000
14	C23	B23	SC23	Static Var Compensator	800.00	345.00	PV	0.00	549.95	549.95	0.0	5.402	800.00	550.00	B23	1.018
15	C04	B04	SC4	Static Var Compensator	300.00	345.00	PV	0.00	277.95	277.95	0.0	2.780	300.00	1.00	B04	1.000
16	C14	B14	SC14	Static Var Compensator	250.00	16.50	PV	0.00	1.05	1.05	0.0	0.010	250.00	1.00	B14	1.000
17	C15	B15	SC15	Static Var Compensator	250.00	345.00	PV	0.00	120.51	120.51	0.0	1.206	250.00	1.00	B15	0.999

Induction motor report

	ID	Bus ID	DBase ID	Type	V sol [pu]	S [MVA]	P. Factor [%]	I [pu]
1	IM1	B23	IM1	Induction Motor	1.018	1000.00	80.0	9.823

Line report

	ID	Bus From	Bus To	DBase ID	Type	kV Nominal	Length	P [MW]	Q [MVAR]	S [MVA]	P. Factor [%]	I [pu]	I angle [deg]	P losses [MW]	Q losses [MVAR]	Ampacity (Norm.) [pu]	Loading %	Ampacity (Emer.) [pu]	Loading(Emer) %
1	L10	B05	B08	L10	Line	345.00	75.1000	238.34	59.04	245.54	97.1	2.490	-24.7	0.50	-7.18	4.780	52.1	5.079	49.0
2	L20	B15	B16	L20	Line	345.00	63.0000	-54.88	-40.55	68.23	-80.4	0.683	128.4	0.04	-16.76	7.171	9.5	10.756	6.3
3	L30	B25	B26	L30	Line	345.00	216.5000	113.32	-17.50	114.66	98.8	1.120	0.1	0.39	-49.45	4.780	23.4	5.079	22.1
4	L11	B06	B07	L11	Line	345.00	61.7000	376.11	69.23	382.43	98.3	3.880	-20.4	0.91	3.04	4.780	81.2	5.079	76.4
5	L21	B16	B17	L21	Line	345.00	59.7000	-71.78	-20.78	74.73	-96.1	0.745	149.0	0.04	-13.05	7.171	10.4	10.756	6.9
6	L31	B26	B27	L31	Line	345.00	98.5000	372.15	50.50	375.56	99.1	3.690	-18.4	1.93	-4.29	4.780	77.2	5.079	72.6
7	L01	B01	B02	L1	Line	345.00	275.5000	250.23	16.11	250.75	99.8	2.412	-8.0	2.12	-48.75	4.780	50.5	5.079	47.5
8	L12	B06	B11	L12	Line	345.00	55.0000	-273.28	-97.04	290.00	-94.2	2.942	150.5	0.60	-6.64	7.171	41.0	10.756	27.4
9	L22	B16	B19	L22	Line	345.00	130.7000	-648.23	131.27	661.39	-98.0	6.594	176.6	7.03	55.34	10.756	61.3	16.134	40.9
10	L32	B26	B28	L32	Line	345.00	317.7000	-174.54	-16.41	175.31	-99.6	1.722	164.0	1.29	-66.59	4.780	36.0	5.079	33.9
11	L02	B01	B39	L2	Line	345.00	167.6000	248.38	-6.72	248.48	100.0	2.391	-2.7	0.58	-70.63	4.780	50.0	5.079	47.1
12	L13	B07	B08	L13	Line	345.00	30.8000	141.41	-17.82	142.52	99.2	1.459	-4.8	0.08	-6.47	4.780	30.5	5.079	28.7
13	L23	B16	B21	L23	Line	345.00	90.5000	35.70	-32.63	48.37	73.8	0.482	27.6	0.01	-25.46	4.780	10.1	5.079	9.5
14	L33	B26	B29	L33	Line	345.00	418.9000	-223.69	-19.14	224.50	-99.6	2.206	164.5	2.82	-75.80	4.780	46.1	5.079	43.4
15	L03	B02	B03	L3	Line	345.00	101.2000	446.26	18.96	446.67	99.9	4.404	-12.2	2.53	3.13	4.780	92.1	5.079	86.7
16	L14	B08	B09	L14	Line	345.00	243.3000	-142.85	-121.14	187.29	-76.3	1.917	127.3	0.75	-26.20	4.780	40.1	5.079	37.7
17	L24	B16	B24	L24	Line	345.00	39.5000	300.40	-133.96	328.92	91.3	3.279	9.2	0.32	-0.60	4.780	68.6	5.079	64.6
18	L34	B28	B29	L34	Line	345.00	101.2000	-381.83	22.58	382.49	-99.8	3.760	177.4	1.99	-4.35	4.780	78.6	5.079	74.0
19	L04	B02	B25	L4	Line	345.00	57.6000	-198.12	45.96	203.38	-97.4	2.005	-176.7	2.86	-11.64	4.780	41.9	5.079	39.5
20	L15	B09	B39	L15	Line	345.00	167.6000	-143.59	-94.94	172.14	-83.4	1.688	137.0	0.21	-120.87	4.780	35.3	5.079	33.2
21	L25	B17	B18	L25	Line	345.00	55.0000	17.31	2.66	17.51	98.8	0.174	-23.2	0.00	-13.27	4.780	3.6	5.079	3.4
22	L05	B03	B04	L5	Line	345.00	142.8000	-19.18	18.34	26.53	-72.3	0.264	-149.8	0.02	-22.01	4.780	5.5	5.079	5.2
23	L16	B10	B11	L16	Line	345.00	28.8000	286.81	77.53	297.10	96.5	2.971	-23.1	0.36	-3.44	7.171	41.4	10.756	27.6
24	L26	B17	B27	L26	Line	345.00	116.0000	-89.12	-10.38	89.72	-99.3	0.893	158.8	0.10	-31.10	4.780	18.7	5.079	17.6
25	L06	B03	B18	L6	Line	345.00	89.1000	140.91	-4.90	141.00	99.9	1.402	-11.5	0.22	-18.98	4.780	29.3	5.079	27.6
26	L17	B10	B13	L17	Line	345.00	28.8000	460.27	-42.52	462.23	99.6	4.622	-2.7	0.85	1.89	4.780	96.7	5.079	91.0
27	L27	B21	B22	L27	Line	345.00	93.8000	-238.31	-122.18	267.81	-89.0	2.664	137.7	0.54	-16.87	7.171	37.1	10.756	24.8
28	L07	B04	B05	L7	Line	345.00	85.8000	-323.38	127.99	347.78	-93.0	3.478	-171.7	0.98	2.47	4.780	72.8	5.079	68.5
29	L18	B13	B14	L18	Line	345.00	67.7000	464.49	-40.78	466.27	99.6	4.663	-4.1	1.95	4.66	4.780	97.5	5.079	91.8
30	L28	B22	B23	L28	Line	345.00	64.3000	459.04	24.51	459.69	99.9	4.494	-16.4	1.21	0.21	4.780	94.0	5.079	88.5
31	L08	B04	B14	L8	Line	345.00	86.5000	-195.83	6.31	195.93	-99.9	1.959	168.6	0.31	-8.86	4.780	41.0	5.079	38.6
32	L19	B14	B15	L19	Line	345.00	145.4000	266.41	-29.23	268.01	99.4	2.680	-5.6	1.28	-21.16	4.780	56.1	5.079	52.8
33	L29	B23	B24	L29	Line	345.00	234.6000	8.53	4.24	9.53	89.5	0.094	-42.2	0.01	-36.92	4.780	2.0	5.079	1.8
34	L09	B05	B06	L9	Line	345.00	17.4000	-562.69	66.47	566.61	-99.3	5.745	175.9	0.66	4.37	7.171	80.1	10.756	53.4

Result and Observation

The overflows have been removed. We can also check that the overall pf has increased as well, as the SVCs are compensating for the reactive losses. The active power remains almost the same.

Active generation = 6958.375 MW

Reactive generation = 2118.694

Power factor = $\cos(\tan^{-1}(2118.694/6958.375))$ = **0.9566**

Which is an improvement from **0.9289.**

The losses, specially the reactive losses have decreased as well, almost by 1/7 th.

The induction motor voltage is restored to 1pu as well.

The effect of SVC and swing distribution has evidently improved the network condition.

Concluding Discussion

In this project, we have investigated the operation of a real power network. In practical, industrial plants draw a lot of reactive power, and the power distributor often sets a lower limit to the power factor of the plant, below which the industry has to pay significant charges for the line losses caused. This is why, every plant uses a power factor improvement system, that consists of static VAR compensators (that supply constant reactive power locally), synchronous condensers and etc. Power distribution networks often use FACT devices across line to reduce overload as well.

We were unable to simulate synchronous condensers and FACTs in our PSAF, and had to work with SVCs only.

Photovoltaic Generators in task 2 are to be noted as fault current reducing schemes as well.

As a conclusion, we can claim that this was a very good experience of working with a working power distribution system and simulate how to overcome the challenges faced in real time distribution ans power management.