EEE 306 | Project Report

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

---

L-3, T-1

Section: A2

Group No: 02

Submission Date: 26th July, 2021

Submitted to:

Dr. Nahid-Al-Masood

Professor, Dept of EEE, BUET

Suzit Hasan Nayem (PT)

Lecturer, Dept of EEE, BUET

Submitted by,

Name: Deb Indronil Sajib
ID: 1706041

Name: Habibullah Khan
ID: 1706040

Name: Monirul Islam
ID: 1706042

Name: Fariza Siddiqua
ID:1706043

Name: A F M Mahfuzul Kabir
ID: 1706045

Name: Shuvro Chowdhury
ID:1706044

Introduction:

Power flow or load flow is widely used in power system operation and planning. The power flow model of a power system is built using the relevant network, load and generation data. Outputs of the power flow model include voltages at different buses, line flows in the network and system losses. These outputs are obtained by solving nodal power balance equations. Since these equations are non linear, Newton-Raphson, Gauss-Seidel and the Fast-Decoupled methods are commonly used to solve this problem.

Again, the fault analysis of a power system is required in order to provide information for the selection of switchgear, setting of relays and stability of system operation. Faults usually occur in a power system due to either insulation failure, flashover, physical damage or human error. These faults, may either be three phase in nature involving all three phases in a symmetrical manner, or may be asymmetrical where usually only one or two phases may be involved.

In this project we had to complete 5 tasks in total. The objectives of the tasks are to –

1. Perform load flow analysis of IEEE 39-Bus System.
2. Find circuit breaker rating of all generator buses by performing symmetrical fault analysis.
3. Observing change in fault current if photovoltaic generator is connected.
4. Observe line overloading when an induction motor is connected.
5. Finally design a solution to mitigate line overloading.

Task-1:

In case of taking inputs, we have taken BUS, LINE, TRANSFORMER, GENERATORS and LOADS.

For BUS input we entered base voltage and operating voltage. Noteworthy fact is that except for buses which are connected to generators, belong to same base and operating voltages. As of , generator connected buses(Bus 30,31,32,33,34,35,36,37,38,39) we have multiplied specified generation voltages with base voltage to get the value of operating voltage.

For lines, the given p.u. R and X was for full length. So, while entering value we have divided for having values per k.m. Also, the given R and X was positive sequence impedance. Moreover, individual Loading limit and Emergency limit was assigned.

For transformer input, R and X was provided. So we calculated z=sqrt(R^2+x^2). And the R/X ratio is as the parameter suggests.

For generator section,combining Table 04 and Table 05 data was taken. G05 was duplic . Except for slack generator active power was entered as the table suggested.

For static load we had to assign P & Q in the database ID section as well as in the table.

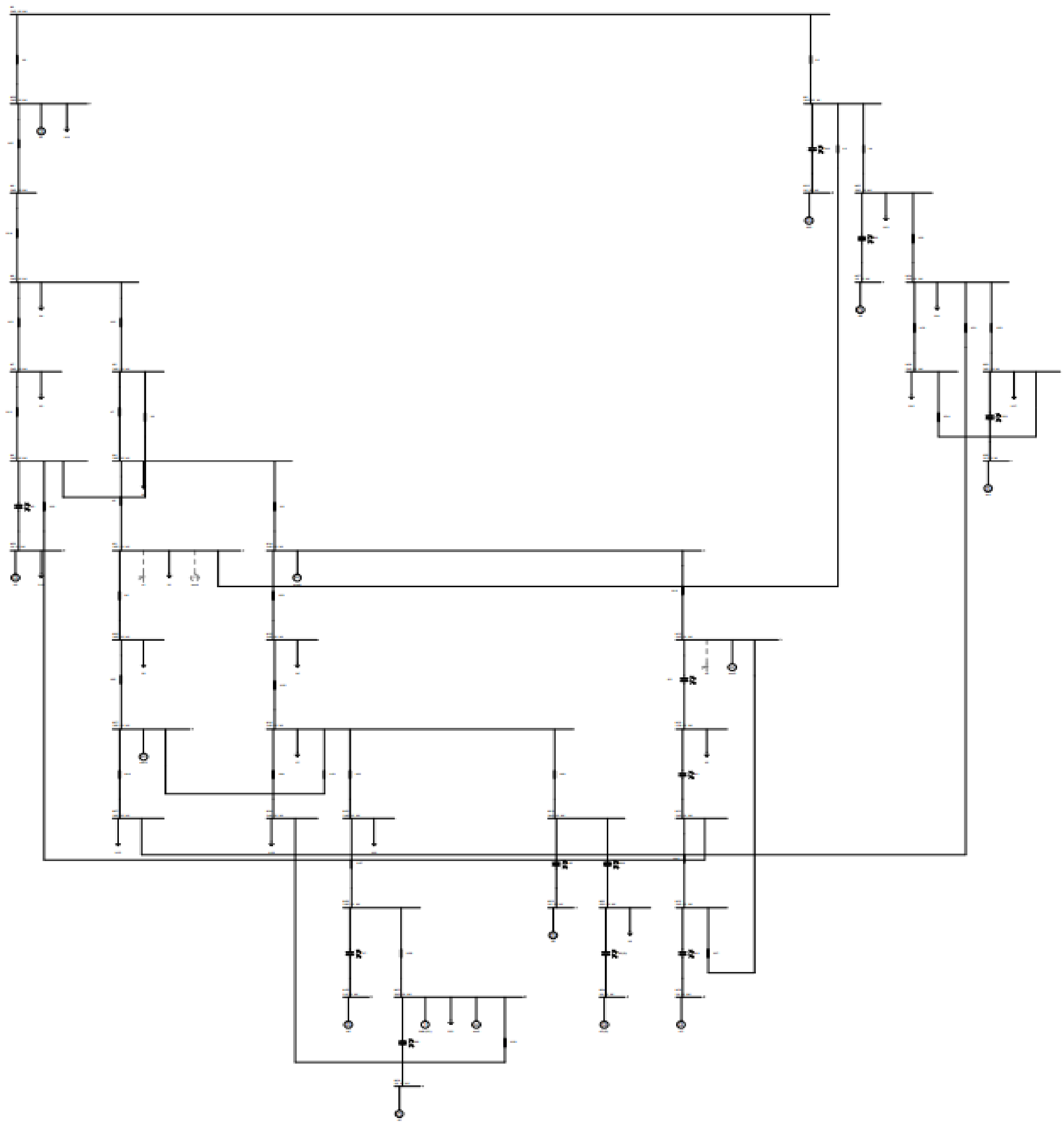

Figure: PSAF generated One Line Diagram of given network

After taking inputs we went to “study” , from monitoring section we selected all the 114 components and then we did LOAD FLOW ANALYSIS with Newton Raphson Method with 60 iterations. After few attemps and correction made in data input, we managed to have converged dataset. Then we saw the text report.

After the input of the 114 components were taken and load flow analysis was performed , we found the result like below:

LOAD FLOW STUDY PARAMETERS	
Study :	UNTITLED
Time :	Sun Jul 25 19h48m43s 2021
Method :	Newton-Raphson
Constraints :	Not applied
Flat start :	Yes
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	**6151.001**	**1369.201**
Spinning reserve	7528.999	
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	33.363	-645.510
Transformer losses	20.538	605.811
Total losses	**53.901**	**-39.699**
Mismatches	0.000	-0.001

Fig: Summary Report

	ID						
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	L30	B25	B26	0.684	2.390		
12	L21	B16	B17	2.438	3.585		
13	L22	B16	B19	5.107	5.378		
14	L32	B26	B28	1.410	2.390		
15	L13	B7	B8	1.993	2.390		
16	L33	B26	B29	1.891	2.390		
17	L14	B8	B9	1.881	2.390		
18	L24	B16	B24	1.481	2.390		
19	L15	B9	B39	1.513	2.390		
20	L25	B17	B18	2.118	2.390		
21	L26	B17	B27	0.651	2.390		
22	L28	B22	B23	0.424	2.390		
23	L19	B14	B15	0.586	2.390		
24	L1	B1	B2	1.235	2.390		
25	L2	B1	B39	1.235	2.390		
26	L5	B3	B4	1.822	2.390		
27	L6	B3	B18	0.521	2.390		
28	L7	B4	B5	1.488	2.390		

29							
30	*OVERLOADED TRANSFORMERS (WITHIN 100 %)*						
31	**ID**	**Bus From**	**Bus To**	**Power Flow - [MVA]**	**Loading Limit - [MVA]**	**Emergency Loading Limit - [MVA]**	
32							
33	*UNDERLOADED TRANSFORMERS (WITHIN 50 %)*						
34	**ID**	**Bus From**	**Bus To**	**Power Flow - [MVA]**	**Loading Limit - [MVA]**		
35	F10	B2	B30	292.080	550.000		
36	F12	B19	B20	123.257	550.000		
37	F1	B12	B11	42.001	250.000		
38	F2	B12	B13	46.566	250.000		
39	F6	B20	B34	513.852	700.000		
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 - [%]**	

Fig: Abnormal Report

The load flow converged. Thus, we can be assured that data has been correctly entered There are some under loaded lines and transformers but no component seems to have an overloaded condition.

Task 2:

In task 2 we are needed to find the circuit breaker rating for the buses connected to the generators.

A circuit breaker is an automatically operated electrical switch designed to protect an electrical circuit from damage caused by excess current from an overload or short circuit. Its basic function is to interrupt current flow after a fault is detected. So, in order to design a circuit breaker, we need to know the current that flows through that circuit in the event of a short circuit.

To find the short circuit current we used the symmetric fault analysis system where Line to Line to Line to Ground fault occur. The reason for this is Line – Line – Line Fault – Such types of faults are balanced, such that, the system remains symmetrical even after the fault. The L – L – L fault occurs rarely, but it is the most severe type of fault which involves the largest current.

In PSAF software we used the ‘Fault Analysis IEC’ system to find the L-L-L fault current for the Generator connected Buses. We used base parameters as Base power 100MVA and frequency 50Hz which are default parameters.

Results:

ID	Type	Prefault kV	Angle	Fault type	Fault S [MVA]	IL1 [KA]	IL1 [deg]	IL2 [KA]	IL2 [deg]	IL3 [KA]	IL3 [deg]	In [KA]	In [deg]
Faulted Bus ->													
B30		16.50	0.00	LLL	10663	373.1199	-86.5862	373.1199	153.4138	373.1199	33.4138	0.0000	0.0000
First Ring Contributions													
G10	Generator	16.50	0.00	LLL	7258	253.9501	-87.1376	253.9501	152.8624	253.9501	32.8624	0.0000	0.0000
F10	Fixed-Tap Xmer	16.50	0.00	LLL	3407	119.2065	-85.4114	119.2065	154.5886	119.2065	34.5886	0.0000	0.0000
Faulted Bus ->													
B31		16.50	0.00	LLL	7374	258.0261	-85.5286	258.0261	154.4714	258.0261	34.4714	0.0000	0.0000
First Ring Contributions													
G2	Generator	16.50	0.00	LLL	4666	163.2826	-84.2894	163.2826	155.7106	163.2826	35.7106	0.0000	0.0000
F3	Fixed-Tap Xmer	16.50	0.00	LLL	2711	94.8475	-87.6624	94.8475	152.3376	94.8475	32.3376	0.0000	0.0000
Faulted Bus ->													
B32		16.50	0.00	LLL	8603	301.0292	-87.1342	301.0292	152.8658	301.0292	32.8658	0.0000	0.0000
First Ring Contributions													
G3	Generator	16.50	0.00	LLL	5806	203.1601	-87.1376	203.1601	152.8624	203.1601	32.8624	0.0000	0.0000
F4	Fixed-Tap Xmer	16.50	0.00	LLL	2797	97.8691	-87.1272	97.8691	152.8728	97.8691	32.8728	0.0000	0.0000

ID	Type	Prefault kV	Angle	Fault type	Fault S [MVA]	IL1 [KA]	IL1 [deg]	IL2 [KA]	IL2 [deg]	IL3 [KA]	IL3 [deg]	In [KA]	In [deg]
Faulted Bus ->													
B33		16.50	0.00	LLL	8758	306.4525	-86.9369	306.4525	153.0631	306.4525	33.0631	0.0000	0.0000
First Ring Contributions													
G4	Generator	16.50	0.00	LLL	5806	203.1601	-87.1376	203.1601	152.8624	203.1601	32.8624	0.0000	0.0000
F5	Fixed-Tap Xmer	16.50	0.00	LLL	2952	103.2961	-86.5422	103.2961	153.4578	103.2961	33.4578	0.0000	0.0000
Faulted Bus ->													
B34		16.50	0.00	LLL	5982	209.2996	-87.0864	209.2996	152.9136	209.2996	32.9136	0.0000	0.0000
First Ring Contributions													
G5	Generator	16.50	0.00	LLL	4355	152.3701	-87.1376	152.3701	152.8624	152.3701	32.8624	0.0000	0.0000
F6	Fixed-Tap Xmer	16.50	0.00	LLL	1627	56.9298	-86.9495	56.9298	153.0505	56.9298	33.0505	0.0000	0.0000
Faulted Bus ->													
B35		16.50	0.00	LLL	8843	309.4247	-87.2199	309.4247	152.7801	309.4247	32.7801	0.0000	0.0000
First Ring Contributions													
G6	Generator	16.50	0.00	LLL	5806	203.1601	-87.1376	203.1601	152.8624	203.1601	32.8624	0.0000	0.0000
F7	Fixed-Tap Xmer	16.50	0.00	LLL	3037	106.2651	-87.3771	106.2651	152.6229	106.2651	32.6229	0.0000	0.0000

ID	Type	Prefault kV	Angle	Fault type	Fault S [MVA]	IL1 [KA]	IL1 [deg]	IL2 [KA]	IL2 [deg]	IL3 [KA]	IL3 [deg]	In [KA]	In [deg]
Faulted Bus ->													
B36		16.50	0.00	LLL	7430	259.9827	-87.3896	259.9827	152.6104	259.9827	32.6104	0.0000	0.0000
First Ring Contributions													
G7	Generator	16.50	0.00	LLL	5080	177.7651	-87.1376	177.7651	152.8624	177.7651	32.8624	0.0000	0.0000
F8	Fixed-Tap Xmer	16.50	0.00	LLL	2350	82.2230	-87.9343	82.2230	152.0657	82.2230	32.0657	0.0000	0.0000
Faulted Bus ->													
B37		16.50	0.00	LLL	7823	273.7501	-85.5200	273.7501	154.4800	273.7501	34.4800	0.0000	0.0000
First Ring Contributions													
G8	Generator	16.50	0.00	LLL	5080	177.7651	-87.1376	177.7651	152.8624	177.7651	32.8624	0.0000	0.0000
F9	Fixed-Tap Xmer	16.50	0.00	LLL	2749	96.1868	-82.5295	96.1868	157.4705	96.1868	37.4705	0.0000	0.0000
Faulted Bus ->													
B38		16.50	0.00	LLL	8790	307.5539	-86.7772	307.5539	153.2228	307.5539	33.2228	0.0000	0.0000
First Ring Contributions													
G9	Generator	16.50	0.00	LLL	7258	253.9501	-87.1376	253.9501	152.8624	253.9501	32.8624	0.0000	0.0000
F11	Fixed-Tap Xmer	16.50	0.00	LLL	1533	53.6326	-85.0707	53.6326	154.9293	53.6326	34.9293	0.0000	0.0000
Faulted Bus ->													
B39		345.00	0.00	LLL	75202	125.8492	-87.1046	125.8492	152.8954	125.8492	32.8954	0.0000	0.0000
First Ring Contributions													
G1	Generator	345.00	0.00	LLL	72576	121.4544	-87.1376	121.4544	152.8624	121.4544	32.8624	0.0000	0.0000
L15	Line	345.00	0.00	LLL	1280	2.1414	-86.7328	2.1414	153.2672	2.1414	33.2672	0.0000	0.0000
L2	Line	345.00	0.00	LLL	1347	2.2542	-85.6784	2.2542	154.3216	2.2542	34.3216	0.0000	0.0000

Table: L-L-L fault analysis for generator connected Buses

From the table we can find the symmetric fault current for the generator connected buses and for the value of K= 1 we can find the circuit breaker ratings as

Bus No.	Generator No.	Short circuit current (kA)	Circuit breaker current ratings (kA)	Circuit breaker voltage ratings (kV)
B30	G10	373.119	373.119	16.5
B31	G02	258.026	258.026	16.5
B32	G03	301.029	301.029	16.5
B33	G04	306.425	306.425	16.5
B34	G05	209.299	209.299	16.5
B35	G06	309.424	309.424	16.5
B36	G07	259.983	259.983	16.5
B37	G08	273.750	273.750	16.5
B38	G09	307.554	307.554	16.5
B39	G01	125.849	125.849	345.0

Task 3:

Task 3 deals with the problem that we have to convert the synchronous generator to PV generator connected to bus 32,33,34,36.

we have modified the required generator in accordance with the data that has given Assuming Qmax=0.2*MVA rating, Qmin= -0.2*MVA, pf = 0.9 for PV generators.

The main objective of the task is that using load flow analysis and performing symmetrical fault analysis sequentially we have to check that for a PV generator, the fault current contribution is approximately equal to its rated Current.

Below we get the data after performing fault analysis….

Firstly we have solved fault analysis using the original subtransient values(X”=0.15pu).We are mainly focusing on subtransient reactance(X”) as changing the value of subtransient resistance(R”)doesn’t change the value of fault current . Without changing the subtransient values of the generator(G3) connected to bus 32, we get the following data where the rated current is not equal to the short circuit fault current.

	ID	Type	Prefault kV	Angle	Fault type	Fault S [MVA]	Ia [A]	Ia [deg]	Ib [A]	Ib [deg]	Ic [A]	Ic [deg]	In [A]	In [deg]
1	Faulted Bus ->													
2														
3	B32		16.50	0.00	LLL	5562	194626.2570	-88.4514	194626.2564	151.5486	194626.2564	31.5486	0.0000	0.0000
4														
5	First Ring Contributions													
6														
7	G3	Generator	16.50	0.00	LLL	3200	111960.9516	-89.2368	111960.9512	150.7632	111960.9512	30.7632	0.0000	0.0000
8	F4	Fixed-Tap Xmer	16.50	0.00	LLL	2363	82690.0159	-87.3878	82690.0157	152.6122	82690.0157	32.6122	0.0000	0.0000
9														
10	Faulted Bus ->													
11														
12	B33		16.50	0.00	LLL	5678	198679.4240	-88.1605	198679.4234	151.8395	198679.4234	31.8395	0.0000	0.0000
13														
14	First Ring Contributions													
15														
16	G4	Generator	16.50	0.00	LLL	3200	111960.9516	-89.2368	111960.9512	150.7632	111960.9512	30.7632	0.0000	0.0000
17	F5	Fixed-Tap Xmer	16.50	0.00	LLL	2480	86763.6277	-86.7714	86763.6275	153.2286	86763.6275	33.2286	0.0000	0.0000
18														

Fig: Fault current for X”=0.15pu

Rough calculation:

taking at the generator(G3) connected to bus 32.

here prefault voltage is 16.5 kV and rated power is 800 MVA.

So,rated current is =800/($\sqrt{3}$ *16.5)=27.9927 kA

which is not equal to the short circuit fault current

111.960 kA.

Now we have increased the subtransient reactance(X”)values of the generator. For different value of X” such that X”=0.5pu,1pu,1.5pu we have found that the rated current is not equal to short circuit fault current. Finally after many iterations, when we put X”=1.77pu and perform fault analysis, we find following report:

	ID	Type	Prefault kV	Angle	Fault type	Fault S [MVA]	IL1 [KA]	IL1 [deg]	IL2 [KA]	IL2 [deg]	IL3 [KA]	IL3 [deg]	In [KA]	In [deg]
1	Faulted Bus ->													
2														
3	B32		16.50	0.00	LLL	3547	124.1184	-87.1346	124.1184	152.8654	124.1184	32.8654	0.0000	0.0000
4														
5	First Ring Contributions													
6														
7	G3	Generator	16.50	0.00	LLL	800	27.9819	-87.1376	27.9819	152.8624	27.9819	32.8624	0.0000	0.0000
8	F4	Fixed-Tap Xmer	16.50	0.00	LLL	2747	96.1365	-87.1338	96.1365	152.8662	96.1365	32.8662	0.0000	0.0000
9														
10	Faulted Bus ->													
11														
12	B33		16.50	0.00	LLL	3256	113.9404	-86.5140	113.9404	153.4860	113.9404	33.4860	0.0000	0.0000
13														
14	First Ring Contributions													
15														
16	G4	Generator	16.50	0.00	LLL	800	27.9819	-87.1376	27.9819	152.8624	27.9819	32.8624	0.0000	0.0000
17	F5	Fixed-Tap Xmer	16.50	0.00	LLL	2457	85.9607	-86.3111	85.9607	153.6889	85.9607	33.6889	0.0000	0.0000
18														
19	Faulted Bus ->													
20														
21	B34		16.50	0.00	LLL	1979	69.2343	-86.8402	69.2343	153.1598	69.2343	33.1598	0.0000	0.0000
22														
23	First Ring Contributions													
24														
25	G5	Generator	16.50	0.00	LLL	600	20.9864	-87.1376	20.9864	152.8624	20.9864	32.8624	0.0000	0.0000
26	F6	Fixed-Tap Xmer	16.50	0.00	LLL	1379	48.2482	-86.7109	48.2482	153.2891	48.2482	33.2891	0.0000	0.0000
27														
28	Faulted Bus ->													
29														
30	B36		16.50	0.00	LLL	2977	104.1621	-87.7272	104.1621	152.2728	104.1621	32.2728	0.0000	0.0000
31														
32	First Ring Contributions													
33														
34	G7	Generator	16.50	0.00	LLL	700	24.4842	-87.1376	24.4842	152.8624	24.4842	32.8624	0.0000	0.0000
35	F8	Fixed-Tap Xmer	16.50	0.00	LLL	2277	79.6796	-87.9084	79.6796	152.0916	79.6796	32.0916	0.0000	0.0000

Fig: Fault current for X”=1.77pu

Rough calculation:

taking at the generator(G3) connected to bus 32.
here prefault voltage is 16.5 KV and rated power is 800 MVA.
so,rated current is =800/($\sqrt{3}$ *16.5)=27.9927 kA
which is approximately equal to the short circuit fault current 27.9819 KA.

taking at the generator(G7) connected to bus 36.
here prefault voltage is 16.5 KV and rated power is 700 MVA.
so,rated current is =700/($\sqrt{3}$ *16.5)=24.4936 KA
which is approximately equal to the fault current 24.4842 KA.

Table: The calculated value of rated current and fault current for X”=1.77pu

Bus	Generator	Bus Voltage (kV)	Rated MVA	Rated current (kA)	Fault current (kA)
32	G3	16.5	800	27.9927	27.9819
33	G4	16.5	800	27.9927	27.9819
34	G5	16.5	600	20.9946	20.9864
36	G7	16.5	700	24.4936	24.4842

Here noted that all the rated current are equal to the fault current at a subtransient values of the generator which is X''=1.77 pu.

The following data we get is after performing power flow analysis with modification to the generator connected to the bus.Here we get abnormalities at generator G3,G5,G7.The fact is that the overloading can be compensated by changing the Q limit.

	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	7.21	250.10	100.0	2.501	560.00	-240.00	B30	1.000
2	G1	B39	G01	Generator	10000.00	345.00	PV	1000.00	261.52	1033.63	96.7	10.035	5600.00	-2400.00	B39	1.030
3	G2	B31	G02	Generator	700.00	16.50	SW	531.07	154.38	553.05	96.0	5.632	392.00	-168.00	B31	0.982
4	G3	B32	G_03	Generator	800.00	16.50	PV	650.00	158.95	669.15	97.1	6.807	160.00	-160.00	B32	0.983
5	G4	B33	G_04	Generator	800.00	16.50	PV	632.00	60.83	634.92	99.5	6.367	160.00	-160.00	B33	0.997
6	G5	B34	G_05	Generator	600.00	16.50	PV	508.00	151.69	530.17	95.8	5.237	120.00	-120.00	B34	1.012
7	G6	B35	G06	Generator	800.00	16.50	PV	650.00	236.63	691.73	94.0	6.592	448.00	-192.00	B35	1.049
8	G7	B36	G_07	Generator	700.00	16.50	PV	560.00	209.99	598.08	93.6	5.624	140.00	-140.00	B36	1.064
9	G8	B37	G08	Generator	700.00	16.50	PV	540.00	78.73	545.71	99.0	5.310	392.00	-168.00	B37	1.028
10	G9	B38	G09	Generator	1000.00	16.50	PV	830.00	67.20	832.72	99.7	8.112	560.00	-240.00	B38	1.027

After the the Q limit of the generator we get the following data table of the generator where the overloading problem have been solved.

	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	7.21	250.10	100.0	2.501	560.00	-240.00	B30	1.000
2	G1	B39	G01	Generator	10000.00	345.00	PV	1000.00	261.52	1033.63	96.7	10.035	5600.00	-2400.00	B39	1.030
3	G2	B31	G02	Generator	700.00	16.50	SW	531.07	154.38	553.05	96.0	5.632	392.00	-168.00	B31	0.982
4	G3	B32	G_03	Generator	800.00	16.50	PV	650.00	158.95	669.15	97.1	6.807	180.00	-180.00	B32	0.983
5	G4	B33	G_04	Generator	800.00	16.50	PV	632.00	60.83	634.92	99.5	6.367	160.00	-160.00	B33	0.997
6	G5	B34	G_05	Generator	600.00	16.50	PV	508.00	151.69	530.17	95.8	5.237	360.00	-360.00	B34	1.012
7	G6	B35	G06	Generator	800.00	16.50	PV	650.00	236.63	691.73	94.0	6.592	448.00	-192.00	B35	1.049
8	G7	B36	G_07	Generator	700.00	16.50	PV	560.00	209.99	598.08	93.6	5.624	250.00	-250.00	B36	1.064
9	G8	B37	G08	Generator	700.00	16.50	PV	540.00	78.73	545.71	99.0	5.310	392.00	-168.00	B37	1.028
10	G9	B38	G09	Generator	1000.00	16.50	PV	830.00	67.20	832.72	99.7	8.112	560.00	-240.00	B38	1.027

Task-4: Here we need to add an industrial plant (induction motor) in the previous IEEE-39 bus network of following properties:

Add the induction motor at Bus 23.

Set,

Duplicity: 10

Motor type: Load factor 1

Load factor 1, 2, 3: 100%

Voltage	345 kV	**Efficiency**	90%
MVA rating	100 MVA	**Speed**	750 RPM
HP rating	96527.69 HP	**Rated frequency**	50 Hz
KW rating	72000 kW	**Sub-transient R**	0.00556
Power factor	0.8	**Sub-transient X**	0.3

After adding the induction motor(IM 1) in the power system, the induction motor properties has been adjusted according to given condition.

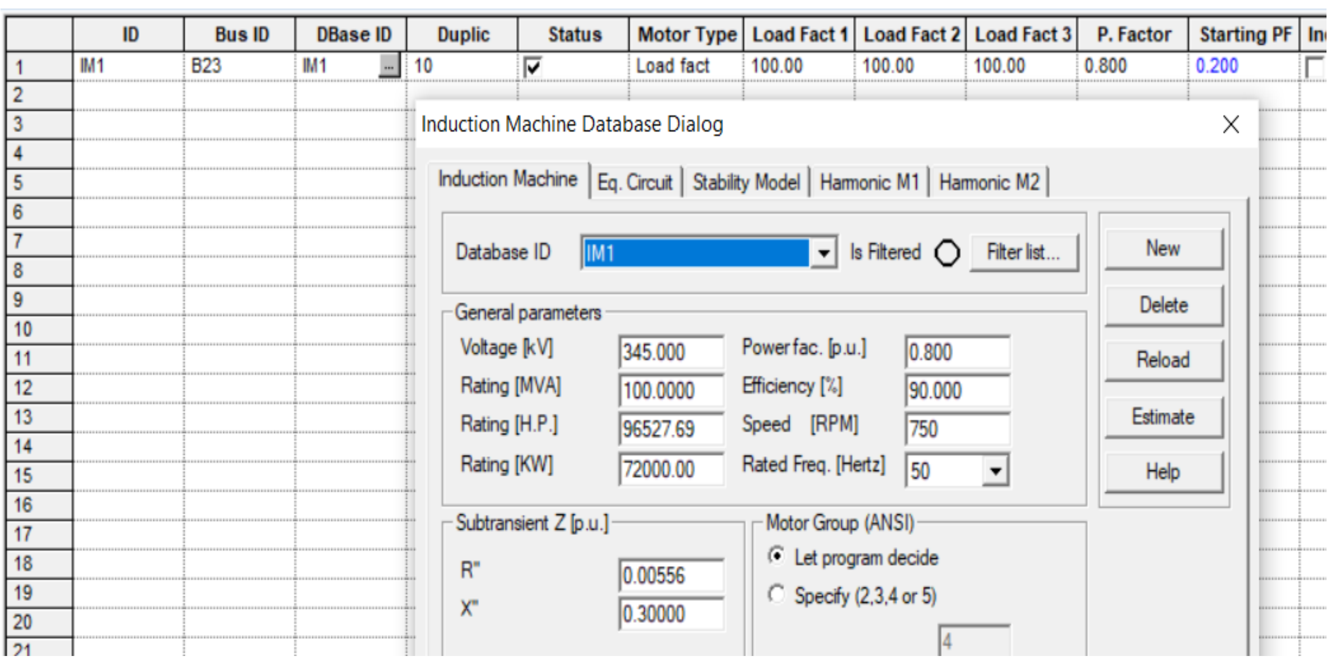

Fig: Induction Motor Data

After performing load flow analysis of the modified network(with 115 components selected) the load flow converged i.e. the data had been entered correctly. The text reports are given below:

Summary report

LOAD FLOW STUDY PARAMETERS	
Study :	ModelGrid4
Time :	Fri Jul 23 23h03m25s 2021
Method :	Newton-Raphson
Constraints :	Not applied
Flat start :	Yes
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	**6989.475**	**2690.454**
Spinning reserve	6980.525	
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	57.703	-476.939
Transformer losses	34.672	1158.494
Total losses	**92.375**	**681.555**
Mismatches	0.000	-0.001

Abnormality Report

	ID						
1							
2	***BUSES OUTSIDE VOLTAGE LIMITS (100 %)***						
3							
4	**Bus ID**	**Zone**	**kV Base**	**Vmin - [v]**	**Vmax - [v]**	**V sol - [v]**	**Ang sol - [deg]**
5	B7	0	345.00	310500.0	379500.0	308506.2	-25.3
6							
7	***OVERLOADED LINES & CABLES (WITHIN 100 %)***						
8	**ID**	**Bus From**	**Bus To**	**Power Flow - [A]**	**Loading Limit - [A]**	**Emergency Loading Limit - [A]**	
9	L11	B6	B7	910.3	800.0	850.0	
10	L17	B10	B13	1021.8	800.0	850.0	
11	L18	B13	B14	1056.3	800.0	850.0	
12	L28	B22	B23	941.6	800.0	850.0	
13	L7	B4	B5	1001.4	800.0	850.0	
14	L9	B5	B6	1643.3	1200.0	1800.0	
15							
16	***UNDERLOADED LINES & CABLES (WITHIN 50 %)***						
17	**ID**	**Bus From**	**Bus To**	**Power Flow - [A]**	**Loading Limit - [A]**		
18	L20	B15	B16	465.9	600.0		
19	L30	B25	B26	260.7	400.0		
20	L21	B16	B17	292.7	600.0		
21	L12	B6	B11	192.1	600.0		
22	L22	B16	B19	882.7	900.0		
23	L32	B26	B28	245.2	400.0		
24	L23	B16	B21	172.8	400.0		
25	L33	B26	B29	325.3	400.0		
26	L25	B17	B18	135.0	400.0		
27	L16	B10	B11	255.9	600.0		
28	L26	B17	B27	178.3	400.0		
29	L27	B21	B22	399.0	600.0		
30	L29	B23	B24	98.9	400.0		
31	L1	B1	B2	65.5	400.0		
32	L2	B1	B39	65.5	400.0		
33	L4	B2	B25	266.2	400.0		
34	L8	B4	B14	275.8	400.0		
36	***OVERLOADED TRANSFORMERS (WITHIN 100 %)***						
37	**ID**	**Bus From**	**Bus To**	**Power Flow - [MVA]**	**Loading Limit - [MVA]**	**Emergency Loading Limit - [MVA]**	
38	F3	B6	B31	1348.2	800.0	850.0	
39							
40	***UNDERLOADED TRANSFORMERS (WITHIN 50 %)***						
41	**ID**	**Bus From**	**Bus To**	**Power Flow - [MVA]**	**Loading Limit - [MVA]**		
42	F10	B2	B30	313.9	550.0		
43	F12	B19	B20	123.8	550.0		
44	F1	B12	B11	49.7	250.0		
45	F2	B12	B13	50.6	250.0		
46	F6	B20	B34	520.0	700.0		
47							
48	***GENERATORS AT REACTIVE LIMITS (WITHIN 0 %)***						
49	**ID**	**Bus From**	**P Gen - [MW]**	**Q Gen - [MVAR]**	**Q Min - [MVAR]**	**Q Max - [MVAR]**	
50	G6	B35	650.00	509.20	-192.00	448.00	
51	G7	B36	560.00	479.61	-168.00	392.00	
52							
53	***TRANSFORMERS AT TAP LIMITS (WITHIN 0 %)***						
54	**ID**	**Bus From**	**Bus To**	**Tap Pos - [v]**	**Min Tap - [v]**	**Max Tap - [v]**	

Before adding the induction motor in the network(with 114 components selected), performing load flow analysis, the summary report and abnormalities report are shown below:

Summary Report

LOAD FLOW STUDY PARAMETERS	
Study :	ModelGrid4
Time :	Sat Jul 24 10h56m31s 2021
Method :	Newton-Raphson
Constraints :	Not applied
Flat start :	Yes
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	**6161.727**	**1382.838**
Spinning reserve	7808.273	
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	44.020	-634.532
Transformer losses	20.606	608.471
Total losses	**64.627**	**-26.061**
Mismatches	0.000	-0.001

Abnormality report

	ID						
1							
2	***BUSES OUTSIDE VOLTAGE LIMITS (100 %)***						
3							
4	**Bus ID**	**Zone**	**kV Base**	**Vmin - [v]**	**Vmax - [v]**	**V sol - [v]**	**Ang sol - [deg]**
5							
6	***OVERLOADED LINES & CABLES (WITHIN 100 %)***						
7	**ID**	**Bus From**	**Bus To**	**Power Flow - [A]**	**Loading Limit - [A]**	**Emergency Loading Limit - [A]**	
8							
9	***UNDERLOADED LINES & CABLES (WITHIN 50 %)***						
10	**ID**	**Bus From**	**Bus To**	**Power Flow - [A]**	**Loading Limit - [A]**		
11	L30	B25	B26	114.0	400.0		
12	L21	B16	B17	408.8	600.0		
13	L22	B16	B19	854.7	900.0		
14	L32	B26	B28	236.0	400.0		
15	L13	B7	B8	372.2	400.0		
16	L33	B26	B29	316.5	400.0		
17	L14	B8	B9	340.0	400.0		
18	L24	B16	B24	248.0	400.0		
19	L15	B9	B39	281.2	400.0		
20	L25	B17	B18	354.9	400.0		
21	L26	B17	B27	109.2	400.0		
22	L28	B22	B23	70.9	400.0		
23	L19	B14	B15	98.3	400.0		
24	L1	B1	B2	208.5	400.0		
25	L2	B1	B39	208.5	400.0		
26	L5	B3	B4	306.3	400.0		
27	L6	B3	B18	87.6	400.0		
28	L7	B4	B5	250.3	400.0		

30	*OVERLOADED TRANSFORMERS (WITHIN 100 %)*						
31	ID	Bus From	Bus To	Power Flow - [MVA]	Loading Limit - [MVA]	Emergency Loading Limit - [MVA]	
32							
33	*UNDERLOADED TRANSFORMERS (WITHIN 50 %)*						
34	ID	Bus From	Bus To	Power Flow - [MVA]	Loading Limit - [MVA]		
35	F10	B2	B30	292.2	550.0		
36	F12	B19	B20	123.2	550.0		
37	F1	B12	B11	42.4	250.0		
38	F2	B12	B13	46.2	250.0		
39	F6	B20	B34	513.9	700.0		
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 - [v]	Min Tap - [v]	Max Tap - [v]	

By comparing the summary report of two networks , we can say,

1. Total active power generation has been increased after adding induction motor.

2.Total reactive power generation has also been increased and has become twice than before.

If we mainly focus now the abnormality report of previous network and the network with induction motor, we can see:

1.Previous there was no overloaded lines, but after adding an induction motor 6lines(Line 11,17,18,26,7,9) have become overloaded.

2.Previous there was no bus outside voltage limits, but now bus B7 has been outside voltage limits.

3.Previous there was no overloaded transformer, but now there is a transformer F3 is in overloaded condition.

4.Previous there was no generator crossing the reactive power limit, but now we have 2 generators(G6 and G7)crossing the reactive power limit.

So, there are many abnormalities which has arrived in the modified network. The reasons behind this are:

(i)We know induction motor needs reactive power to start and continue. As it took reactive power from the system,2 generator(G6 and G7)needed to generate more reactive power to compensate it and as a result the reactive power limit of these two generator crossed.

(ii) Another reason may be, the generators and motor have become clustered around one side of the system and loads have become centered on the other side and power flow from the generator side to the loaded side increases which creates overloading problem of lines and transformers.

(iii)The transformers F3 is overloaded because it is connected with Bus 31 which is a slack bus(if we take a look in the single line diagram of IEEE 39bus power system). So the generator connected with Bus 31 is slack generator and its value is assumed unity $1\angle 0^0$.But when an induction motor is connected to the system, it requires more power. To supply that power slack generator needs to generate more power than it is capable of. That’s why, current passing through transformer F3 passes its limit and the transformer becomes overloaded.

Task-5:

In task 4, we have seen after adding an induction motor to IEEE-39 bus power system, few abnormalities have arrived such as bus undervoltage, line overloading, transformer overloading. There are many correcting measures/devices which can be connected in a power system in order to fix overvoltage/undervoltage problems, such as – static capacitors, synchronous condensers, FACTS devices etc. As our goal is to mitigate the abnormalities in the load flow of the modified network using corrective devices, we have analyzed why it happened and then we have taken following measures to mitigate it:

1.The transformer(F3) overloading problem occurred as transformer was connected to Bus 31 which is a slack bus. As the modified system needed more real power due to the addition of Induction Motor, Slack or swing generator needed to generate more power than its capability, which resulted the transformer overloading and line 11(Bus 6 to Bus 7) overloading. To overcome this, we basically distributed the extra power of swing generator to other generators of the system i.e. increasing the power generation of other generator (Voltage controlled or PV generator) according to the need of the modified power system to release the pressure from swing generator. After iterating and modifying the generator data several times, we found that following distribution of power of other generators would be helpful to solve the overloading problem.

	ID	Bus ID	DBase ID	Duplic	Status	Generator Type	P Gen	Q Desired	Rotor Angle	Ground R	Ground X	Ctrled BusID	Rating
1	G1	B39	G01	1	☑	Voltage C	1000.000	0.000	0.00	9999.000	9999.000	B39	10000.000
2	G10	B30	G10	1	☑	Voltage C	250.000	0.000	0.00	9999.000	9999.000	B30	1000.000
3	G2	B31	G02	1	☑	Swing	0.000	0.000	0.00	9999.000	9999.000	B31	700.000
4	G3	B32	G03	1	☑	Voltage C	650.000	0.000	0.00	9999.000	9999.000	B32	800.000
5	G4	B33	G04	1	☑	Voltage C	632.000	0.000	0.00	9999.000	9999.000	B33	800.000
6	G5	B34	G05	2	☑	Voltage C	254.000	0.000	0.00	9999.000	9999.000	B34	300.000
7	G6	B35	G06	1	☑	Voltage C	650.000	0.000	0.00	9999.000	9999.000	B35	800.000
8	G7	B36	G07	1	☑	Voltage C	560.000	0.000	0.00	9999.000	9999.000	B36	700.000
9	G8	B37	G08	1	☑	Voltage C	540.000	0.000	0.00	9999.000	9999.000	B37	700.000
10	G9	B38	G09	1	☑	Voltage C	830.000	0.000	0.00	9999.000	9999.000	B38	1000.000
11													
12													
13													
14													
15													
16													
17													

Bus | Line | Fixed-Tap Xmer | Generator | Static Load | Induction Motor | Static Var Compensator

Figure: Previous generator data

	ID	Bus ID	DBase ID	Duplic	Status	Generator Type	P Gen	Q Desired	Rotor Angle	Ground R	Ground X	Ctrled BusID	Rating
1	G1	B39	G01	1	☑	Voltage C	1000.000	0.000	0.00	9999.000	9999.000	B39	10000.000
2	G10	B30	G10	1	☑	Voltage C	400.000	0.000	0.00	9999.000	9999.000	B30	1000.000
3	G2	B31	G02	1	☑	Swing	0.000	0.000	0.00	9999.000	9999.000	B31	700.000
4	G3	B32	G03	1	☑	Voltage C	672.000	0.000	0.00	9999.000	9999.000	B32	800.000
5	G4	B33	G04	1	☑	Voltage C	750.000	0.000	0.00	9999.000	9999.000	B33	800.000
6	G5	B34	G05	2	☑	Voltage C	275.000	0.000	0.00	9999.000	9999.000	B34	300.000
7	G6	B35	G06	1	☑	Voltage C	750.000	0.000	0.00	9999.000	9999.000	B35	800.000
8	G7	B36	G07	1	☑	Voltage C	650.000	0.000	0.00	9999.000	9999.000	B36	700.000
9	G8	B37	G08	1	☑	Voltage C	550.000	0.000	0.00	9999.000	9999.000	B37	700.000
10	G9	B38	G09	1	☑	Voltage C	830.000	0.000	0.00	9999.000	9999.000	B38	1000.000
11													
12													
13													
14													
15													
16													
17													

Bus | Line | Fixed-Tap Xmer | **Generator** | Static Load | Induction Motor | Static Var Compensator

Figure: Newly Modified Generator Data

Here we have increased active generation power of a few generators so that load flow converges and overloading problem is solved.

2. In order to solve bus (Bus 7) under voltage problem, line overloading problem, and generator reactive power problem, we have added "**Static Var Compensator"** in several buses to mitigate these problems.

	ID	Bus ID	DBase ID	Duplic	Status	Q	Ctrl'd Bus	L	Q Max	Q Min
1	C1	B23	SVC345	1	☑	1.000	B10	843.80469	450.000	1.000
2	C2	B14	SVC345	1	☑	1.000	B23	843.805	450.000	1.000
3	C3	B13	SVC345	1	☑	1.000	B14	843.805	450.000	1.000
4	C4	B17	SVC345	1	☑	1.000	B13	843.805	450.000	1.000
5	C5	B7	SVC345	1	☑	1.000	B17	843.805	450.000	1.000
6										
7										
8										
9										
10										
11										
12										
13										
14										
15										
16										
17										
18										
19										
20										
21										
22										
23										
24										
25										
26										
27										

Generator | Bus | Line | Static Load | Fixed-Tap Xmer | Induction Motor | **Static Var Compensator**

Figure: Static Var Compensator Data

Here we have added C5 at Bus 7 to solve its under voltage problem, and other SVC in different buses with a view to solving line overloading problem that came up during the time of iteration.

After modifying the generators and adding static var compensator data to our system, when we performed load flow analysis, load flow converged(means our given data was correct) and following reports are found:

LOAD FLOW STUDY PARAMETERS	
Study :	ModelGrid4
Time :	Sun Jul 25 23h02m03s 2021
Method :	Newton-Raphson
Constraints :	Not applied
Flat start :	Yes
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	**6966.668**	**2122.754**
Spinning reserve	6713.332	
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	43.219	-692.335
Transformer losses	26.349	806.190
Total losses	**69.568**	**113.855**
Mismatches	0.000	-0.001

Fig: Summary 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	1.425	3.585		
12	L30	B25	B26	1.412	2.390		
13	L21	B16	B17	0.771	3.585		
14	L12	B6	B11	2.794	3.585		
15	L32	B26	B28	1.400	2.390		
16	L13	B7	B8	2.158	2.390		
17	L23	B16	B21	0.315	2.390		
18	L33	B26	B29	1.881	2.390		
19	L14	B8	B9	1.566	2.390		
20	L15	B9	B39	1.189	2.390		
21	L25	B17	B18	0.371	2.390		
22	L16	B10	B11	2.931	3.585		
23	L26	B17	B27	0.644	2.390		
24	L27	B21	B22	3.185	3.585		
25	L19	B14	B15	2.161	2.390		
26	L29	B23	B24	0.526	2.390		
27	L1	B1	B2	1.058	2.390		
28	L2	B1	B39	1.058	2.390		
29	L4	B2	B25	1.889	2.390		
30	L5	B3	B4	0.955	2.390		
31	L6	B3	B18	1.212	2.390		
32							
33	***OVERLOADED TRANSFORMERS (WITHIN 100 %)***						
34	ID	Bus From	Bus To	Power Flow - [MVA]	Loading Limit - [MVA]	Emergency Loading Limit - [MVA]	
35							
36	***UNDERLOADED TRANSFORMERS (WITHIN 50 %)***						
37	ID	Bus From	Bus To	Power Flow - [MVA]	Loading Limit - [MVA]		
38	F10	B2	B30	413.096	550.000		
39	F12	B19	B20	81.830	550.000		
40	F1	B12	B11	29.019	250.000		
41	F2	B12	B13	61.624	250.000		
42	F6	B20	B34	555.084	700.000		
43							
44	***GENERATORS AT REACTIVE LIMITS (WITHIN 0 %)***						
45	ID	Bus From	P Gen - [MW]	Q Gen - [MVAR]	Q Min - [MVAR]	Q Max - [MVAR]	
46							
47	***TRANSFORMERS AT TAP LIMITS (WITHIN 0 %)***						
48	ID	Bus From	Bus To	Tap Pos - [%]	Min Tap - [%]	Max Tap - [%]	

Fig: Abnormality report

From the abnormality report, there is some underloaded line and transformerfers but no line or transformer is overloaded. Also the issue of undervoltage of a bus and crossing reactive power limit of generator is also solved.

So we have been successfully able to recover the under voltage problem, line and transformer overloading problem which rose at task-4. Here we didn’t need to bring any fundamental change to the network, which includes:

- Adding/deleting an existing line
- Adding/deleting an existing load (i.e. static load)
- Adding/deleting an existing generator
- Adding/deleting an existing transformer.

In this way, we were able to mitigate the abnormalities in the load flow of the modified network using static var compensator and changing active generation power of transformer.

Discussion:

In the whole project(from task-1 to task-5),we mainly worked on two important analysis(Load flow and Fault analysis) to materialize the given IEEE-39 bus power system using CYME PSAF. In task-1, we gave input data of bus, line, fixed tap transformer, generator and static load of the power system in the software and load flow converged. In task-2, we determined the rating of capacitor bank using” Fault Analysis”. In task-3, we modified some generator data to convert it into a PV generator and determined the value of sub transient reactance for which the fault current would be equal to rated current using fault analysis. In task-4, we added an induction motor in the system and observed that some abnormalities arrived. In task-5, we took some measures to overcome those abnormalities and became successful. In terms of continuing the project, we learned a lot about how a large power system works, how load flow and fault analysis is performed, how abnormalities can take place in a power system and what to do to mitigate those abnormalities. It enlarged our knowledge in power system.