Bangladesh University of Engineering and Technology
Department of Electrical & Electronic Engineering

Course No:	EEE 306	**Section:**	A2
Course Title:	Power System I Laboratory	**L/T:**	3/1

Project Name:

Investigating the effect of HVDC Connection

and

Large Industrial Loads in IEEE 39-bus Network

Submitted To:

Dr. Nahid-Al-Masood, Associate Professor

Suzit Hasan Nayem, Lecturer (PT)

Department of Electrical and Electronic Engineering

BUET, Dhaka-1000

Submitted By:

Group No: 4

Sariha Noor Azad (1706051)

Nazmus Salehin (1706052)

Saleh Ahmed Khan (1706053)

Tiasa Mondal (1706054)

Adib Md. Ridwan (1706055)

Introduction:

Power System Analysis is an important field of study in Electrical and Electronic Engineering as it deals with the transmission of power that required to run every aspect of our lives.

In our project, we are investigating an IEEE 39-Bus test system, by introducing Photovoltaic Generators and Heavy Industrial loads in the system and inspecting the results and system behavior as well as figure out the possible ways for the system to adapt to the new changes. This system is also used in many practical applications of power system study, such as the study of simultaneous damping of local and inter-are modes in a system with highly symmetrical structure.

IEEE 39-Bus System

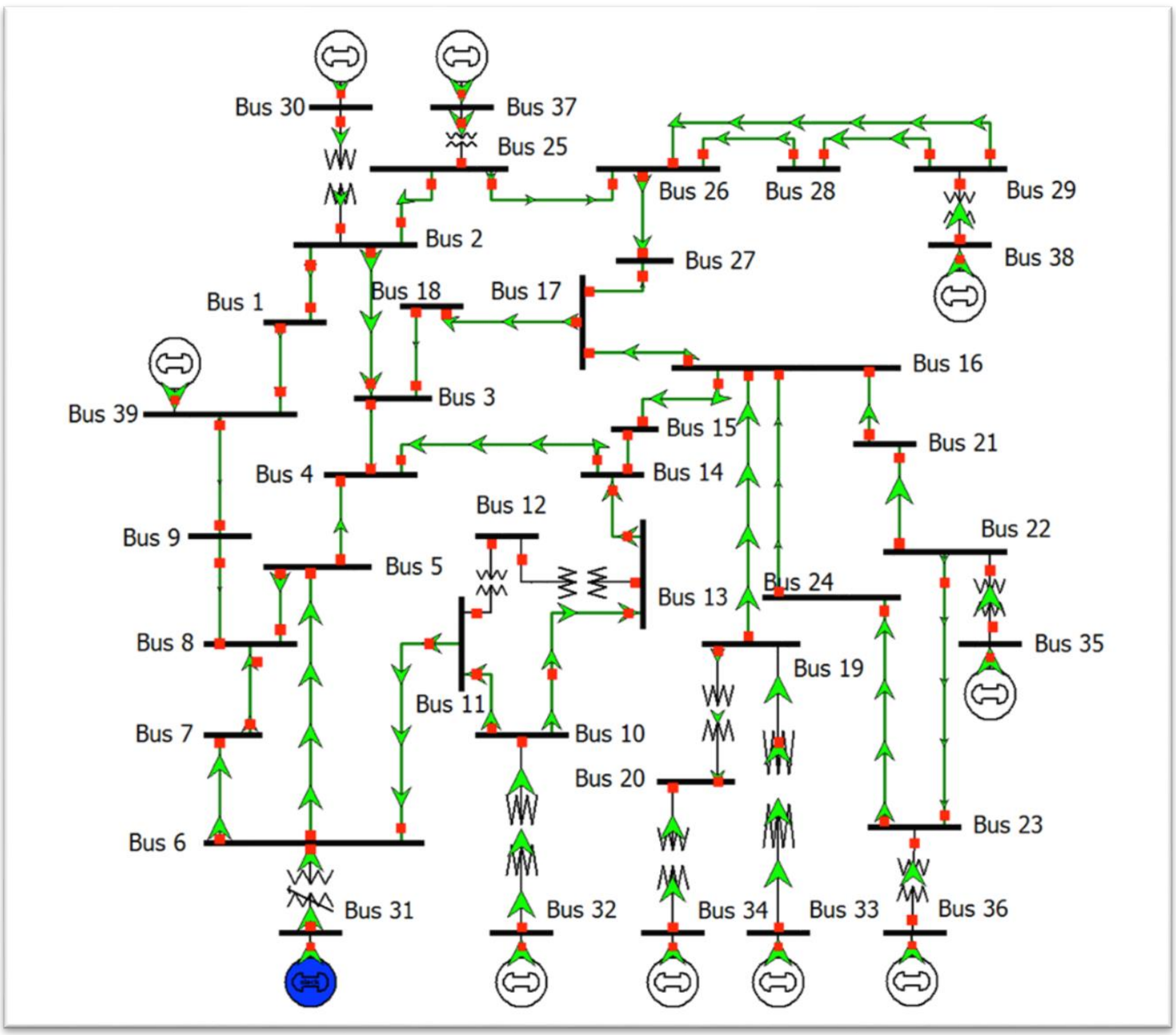


Figure: Single Line Diagram of the System

Overview of the System

Power System Name: *10 Machine New England Power System*

Nominal Frequency: 50 Hz

Number of Buses: 39

Number of Lines: 34

Number of Generators: 10

Number of Induction Motors: 10

Task 1

Power Flow Analysis of Base Case

After entering all the values specified in the datasheet and assuming values for any other necessary parameters, power flow analysis is performed.

Analysis Type: Newton-Raphson solver with Flat Start and No Constraints.

Summary Report

LOAD FLOW STUDY PARAMETERS	
Study :	ModelGrid7
Time :	Sun Jul 18 22h04m02s 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]

Figure: Load flow study parameters (task 1)

COMPLETE SUMMARY REPORT

Summary Data	**Active Power**	**Reactive Power**
Total generation	**6151.363**	**1378.503**
Spinning reserve	7528.637	
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	33.699	-637.283
Transformer losses	20.565	606.886
Total losses	**54.264**	**-30.397**
Mismatches	-0.000	-0.001

Figure: Complete summary report (task 1)

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 - [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	322.3	400.0		
12	L21	B16	B17	471.2	600.0		
13	L12	B6	B11	594.8	600.0		
14	L22	B16	B19	854.6	900.0		
15	L32	B26	B28	227.9	400.0		
16	L33	B26	B29	308.3	400.0		
17	L14	B7	B9	310.9	400.0		
18	L24	B16	B24	247.3	400.0		
19	L15	B9	B39	249.2	400.0		
20	L26	B17	B27	119.7	400.0		
21	L28	B22	B23	71.0	400.0		
22	L19	B10	B15	125.9	400.0		
23	L1	B1	B2	207.6	400.0		
24	L2	B1	B39	207.6	400.0		
25	L5	B3	B4	344.2	400.0		
26	L6	B3	B18	186.3	400.0		
27	L7	B4	B5	212.1	400.0		
28							
29	***OVERLOADED TRANSFORMERS (WITHIN 100 %)***						
30	**ID**	**Bus From**	**Bus To**	**Power Flow - [MVA]**	**Loading Limit - [MVA]**	**Emergency Loading Limit - [MVA]**	
31							
32	***UNDERLOADED TRANSFORMERS (WITHIN 50 %)***						
33	**ID**	**Bus From**	**Bus To**	**Power Flow - [MVA]**	**Loading Limit - [MVA]**		
34	T10	B2	B30	302.6	550.0		
35	T01	B12	B11	43.3	250.0		
36	T02	B12	B13	45.4	250.0		
37	T12	B19	B20	123.3	550.0		
38	T06	B20	B34	513.8	700.0		
39							
40	***GENERATORS AT REACTIVE LIMITS (WITHIN 0 %)***						
41	**ID**	**Bus From**	**P Gen - [MW]**	**Q Gen - [MVAR]**	**Q Min - [MVAR]**	**Q Max - [MVAR]**	
42							
43	***TRANSFORMERS AT TAP LIMITS (WITHIN 0 %)***						
44	**ID**	**Bus From**	**Bus To**	**Tap Pos - [%]**	**Min Tap - [%]**	**Max Tap - [%]**	

Figure: Abnormal report (task 3)

As the load flow calculation converged and there are no abnormalities to be seen. Although, there are a few underloaded lines and transformers.

So, we can conclude, all data has been entered correctly.

Task 2

Circuit Breaker Ratings for Generators in Base Case

According to IEEE definition, Circuit Breaker is a device designed to open and close a circuit by non-automatic means, and to open the circuit automatically on a predetermined overcurrent without damage to itself when properly applied within its rating.

For circuit breaker rating, we have to consider following two facts-

- The maximum instantons current which the breaker must carry (withstand)
- The total Current when the breaker contacts part to interrupt the circuit

Contribution of Generator Current Before Faults

	ID	Bus ID	DBase ID	Type	Rated S [MVA]	kV Nominal	Generator Type	P [MW]	Q [MVAR]	S [MVA]	P. Factor [%]	I [A]
1	G10	B30	G10	Generator	1000.00	17.28	PV	250.00	96.49	267.97	93.3	9376.7
2	G01	B39	G01	Generator	10000.00	355.35	PV	1000.00	196.55	1019.13	98.1	1705.5
3	G02	B31	G02	Generator	700.00	16.20	SW	532.69	227.98	579.42	91.9	20274.6
4	G03	B32	G03	Generator	800.00	16.22	PV	650.00	237.60	692.06	93.9	24216.0
5	G04	B33	G04	Generator	800.00	16.45	PV	632.00	137.18	646.72	97.7	22629.2
6	G05	B34	G05	Generator	300.00	16.70	PV	508.00	130.91	524.60	96.8	18356.1
7	G06	B35	G06	Generator	800.00	17.31	PV	650.00	179.74	674.39	96.4	23597.6
8	G07	B36	G07	Generator	700.00	17.55	PV	560.00	133.66	575.73	97.3	20145.3
9	G08	B37	G08	Generator	700.00	16.96	PV	540.00	63.77	543.75	99.3	19026.4
10	G09	B38	G09	Generator	1000.00	16.94	PV	830.00	28.98	830.51	99.9	29060.2

Figure: Contribution of Generator Current Before Faults (Task 2)

Contribution of Generators to Faults

	ID	Type	Prefault kV	Angle	Fault type	Fault S [MVA]	IL1 [A]	IL1 [deg]	IL2 [A]	IL2 [deg]	IL3 [A]	IL3 [deg]	In [A]	In [deg]
1	**Faulted Bus ->**													
2														
3	B30		16.50	0.00	LLL	9765	341703.7136	-86.3436	341703.7125	153.6564	341703.7125	33.6564	0.0000	0.0000
4	B30		16.50	0.00	LG	0.4	13.5835	-0.0097	0.0000	0.0000	0.0000	0.0000	13.5835	-0.0097
5														
6	**First Ring Contributions**													
7														
8	G10	Generator	16.50	0.00	LLL	6314	220936.5499	-87.1376	220936.5492	152.8624	220936.5492	32.8624	0.0000	0.0000
9		Generator	16.50	0.00	LG	0.3	10.3924	-0.1929	1.5444	0.6491	1.6050	0.6246	13.5415	0.0000
10	T10	Fixed-Tap Xmer	16.50	0.00	LLL	3453	120827.1953	-84.8917	120827.1949	155.1083	120827.1949	35.1083	0.0000	0.0000
11		Fixed-Tap Xmer	16.50	0.00	LG	0.1	3.2199	1.2454	1.6100	-178.7546	1.6100	-178.7546	0.0000	0.0000
12														
13	**Faulted Bus ->**													
14														
15	B31		16.50	0.00	LLL	7150	250195.9950	-85.5719	250195.9941	154.4281	250195.9941	34.4281	0.0000	0.0000
16	B31		16.50	0.00	LG	0.4	13.0481	-0.0103	0.0000	0.0000	0.0000	0.0000	13.0481	-0.0103
17														
18	**First Ring Contributions**													
19														
20	G02	Generator	16.50	0.00	LLL	4425	154845.3746	-84.2894	154845.3741	155.7106	154845.3741	35.7106	0.0000	0.0000
21		Generator	16.50	0.00	LG	0.3	9.7277	0.4122	1.7055	-1.1756	1.5844	-1.2655	13.0166	-0.0000
22	T03	Fixed-Tap Xmer	16.50	0.00	LLL	2728	95452.3734	-87.6527	95452.3731	152.3473	95452.3731	32.3473	0.0000	0.0000
23		Fixed-Tap Xmer	16.50	0.00	LG	0.1	3.2908	-1.8280	1.6151	178.1377	1.6757	178.2051	0.0000	0.0000

	ID	Type	Prefault kV	Angle	Fault type	Fault S [MVA]	IL1 [A]	IL1 [deg]	IL2 [A]	IL2 [deg]	IL3 [A]	IL3 [deg]	In [A]	In [deg]
24														
25	**Faulted Bus ->**													
26														
27	B32		16.50	0.00	LLL	9133	319556.8032	-87.1902	319556.8021	152.8098	319556.8021	32.8098	0.0000	0.0000
28	B32		16.50	0.00	LG	0.4	14.4652	-0.0100	0.0000	0.0000	0.0000	0.0000	14.4652	-0.0100
29														
30	**First Ring Contributions**													
31														
32	G03	Generator	16.50	0.00	LLL	6111	213824.4829	-87.1376	213824.4822	152.8624	213824.4822	32.8624	0.0000	0.0000
33		Generator	16.50	0.00	LG	0.3	11.2671	0.0000	1.6096	0.0000	1.6096	0.0000	14.4862	0.0000
34	T04	Fixed-Tap Xmer	16.50	0.00	LLL	3022	105732.5953	-87.2966	105732.5950	152.7034	105732.5950	32.7034	0.0000	0.0000
35		Fixed-Tap Xmer	16.50	0.00	LG	0.1	3.2192	0.0000	1.6096	180.0000	1.6096	180.0000	0.0000	0.0000
36														
37	**Faulted Bus ->**													
38														
39	B33		16.50	0.00	LLL	8771	306914.7936	-86.9323	306914.7926	153.0677	306914.7926	33.0677	0.0000	0.0000
40	B33		16.50	0.00	LG	0.4	14.2658	-0.0100	0.0000	0.0000	0.0000	0.0000	14.2658	-0.0100
41														
42	**First Ring Contributions**													
43														
44	G04	Generator	16.50	0.00	LLL	5855	204868.7873	-87.1376	204868.7866	152.8624	204868.7866	32.8624	0.0000	0.0000
45		Generator	16.50	0.00	LG	0.3	11.1272	-0.1802	1.5444	0.6491	1.6050	0.6246	14.2763	-0.0000
46	T05	Fixed-Tap Xmer	16.50	0.00	LLL	2916	102050.0233	-86.5203	102050.0230	153.4797	102050.0230	33.4797	0.0000	0.0000
47		Fixed-Tap Xmer	16.50	0.00	LG	0.1	3.1492	0.0000	1.5746	180.0000	1.5746	180.0000	0.0000	0.0000
48														

	ID	Type	Prefault kV	Angle	Fault type	Fault S [MVA]	IL1 [A]	IL1 [deg]	IL2 [A]	IL2 [deg]	IL3 [A]	IL3 [deg]	In [A]	In [deg]
48														
49	**Faulted Bus ->**													
50														
51	B34		16.50	0.00	LLL	4414	154463.3741	-87.0068	154463.3736	152.9932	154463.3736	32.9932	0.0000	0.0000
52	B34		16.50	0.00	LG	0.4	14.0559	-0.0124	0.0000	0.0000	0.0000	0.0000	14.0559	-0.0124
53														
54	**First Ring Contributions**													
55														
56	G05	Generator	16.50	0.00	LLL	2099	73440.9349	-87.1376	73440.9347	152.8624	73440.9347	32.8624	0.0000	0.0000
57		Generator	16.50	0.00	LG	0.3	9.1676	0.0000	2.4494	0.0000	2.4494	0.0000	14.0664	0.0000
58	T06	Fixed-Tap Xmer	16.50	0.00	LLL	2316	81022.8166	-86.8883	81022.8163	153.1117	81022.8163	33.1117	0.0000	0.0000
59		Fixed-Tap Xmer	16.50	0.00	LG	0.1	4.8987	0.0000	2.4494	180.0000	2.4494	180.0000	0.0000	0.0000
60														
61	**Faulted Bus ->**													
62														
63	B35		16.50	0.00	LLL	8040	281340.1047	-87.2177	281340.1038	152.7823	281340.1038	32.7823	0.0000	0.0000
64	B35		16.50	0.00	LG	0.4	13.5520	-0.0101	0.0000	0.0000	0.0000	0.0000	13.5520	-0.0101
65														
66	**First Ring Contributions**													
67														
68	G06	Generator	16.50	0.00	LLL	5026	175862.5191	-87.1376	175862.5185	152.8624	175862.5185	32.8624	0.0000	0.0000
69		Generator	16.50	0.00	LG	0.3	10.1824	-0.0000	1.6796	0.0000	1.6796	0.0000	13.5415	-0.0000
70	T07	Fixed-Tap Xmer	16.50	0.00	LLL	3014	105478.0678	-87.3512	105478.0675	152.6488	105478.0675	32.6488	0.0000	0.0000
71		Fixed-Tap Xmer	16.50	0.00	LG	0.1	3.3591	0.0000	1.6796	180.0000	1.6796	180.0000	0.0000	0.0000
72														

	ID	Type	Prefault kV	Angle	Fault type	Fault S [MVA]	IL1 [A]	IL1 [deg]	IL2 [A]	IL2 [deg]	IL3 [A]	IL3 [deg]	In [A]	In [deg]
72														
73	**Faulted Bus ->**													
74														
75	B36		16.50	0.00	LLL	6555	229351.9668	-87.4146	229351.9660	152.5854	229351.9660	32.5854	0.0000	0.0000
76	B36		16.50	0.00	LG	0.4	13.3735	-0.0106	0.0000	0.0000	0.0000	0.0000	13.3735	-0.0106
77														
78	**First Ring Contributions**													
79														
80	G07	Generator	16.50	0.00	LLL	4223	147779.9466	-87.1376	147779.9461	152.8624	147779.9461	32.8624	0.0000	0.0000
81		Generator	16.50	0.00	LG	0.3	10.1824	0.0000	1.5746	0.0000	1.5746	0.0000	13.3315	0.0000
82	T08	Fixed-Tap Xmer	16.50	0.00	LLL	2331	81576.8750	-87.9164	81576.8748	152.0836	81576.8748	32.0836	0.0000	0.0000
83		Fixed-Tap Xmer	16.50	0.00	LG	0.1	3.1494	-0.6366	1.6050	179.3754	1.5444	179.3509	0.0000	0.0000
84														
85	**Faulted Bus ->**													
86														
87	B37		16.50	0.00	LLL	7612	266355.6557	-86.0210	266355.6548	153.9790	266355.6548	33.9790	0.0000	0.0000
88	B37		16.50	0.00	LG	0.4	13.8354	-0.0103	0.0000	0.0000	0.0000	0.0000	13.8354	-0.0103
89														
90	**First Ring Contributions**													
91														
92	G08	Generator	16.50	0.00	LLL	4679	163718.4720	-87.1376	163718.4715	152.8624	163718.4715	32.8624	0.0000	0.0000
93		Generator	16.50	0.00	LG	0.3	10.2876	-0.3898	1.7243	1.1628	1.8455	1.0864	13.8564	0.0000
94	T09	Fixed-Tap Xmer	16.50	0.00	LLL	2936	102717.8577	-84.2411	102717.8574	155.7589	102717.8574	35.7589	0.0000	0.0000
95		Fixed-Tap Xmer	16.50	0.00	LG	0.1	3.5718	2.2457	1.7859	-177.7543	1.7859	-177.7543	0.0000	0.0000
96														

	ID	Type	Prefault kV	Angle	Fault type	Fault S [MVA]	IL1 [A]	IL1 [deg]	IL2 [A]	IL2 [deg]	IL3 [A]	IL3 [deg]	In [A]	In [deg]
88	B37		16.50	0.00	LG	0.4	13.8354	-0.0103	0.0000	0.0000	0.0000	0.0000	13.8354	-0.0103
89														
90	**First Ring Contributions**													
91														
92	G08	Generator	16.50	0.00	LLL	4679	163718.4720	-87.1376	163718.4715	152.8624	163718.4715	32.8624	0.0000	0.0000
93		Generator	16.50	0.00	LG	0.3	10.2876	-0.3898	1.7243	1.1628	1.8455	1.0864	13.8564	0.0000
94	T09	Fixed-Tap Xmer	16.50	0.00	LLL	2936	102717.8577	-84.2411	102717.8574	155.7589	102717.8574	35.7589	0.0000	0.0000
95		Fixed-Tap Xmer	16.50	0.00	LG	0.1	3.5718	2.2457	1.7859	-177.7543	1.7859	-177.7543	0.0000	0.0000
96														
97	**Faulted Bus ->**													
98														
99	B38		16.50	0.00	LLL	7906	276620.8253	-86.7088	276620.8244	153.2912	276620.8244	33.2912	0.0000	0.0000
100	B38		16.50	0.00	LG	0.4	13.8564	-0.0101	0.0000	0.0000	0.0000	0.0000	13.8564	-0.0101
101														
102	**First Ring Contributions**													
103														
104	G09	Generator	16.50	0.00	LLL	6710	234796.0816	-87.1376	234796.0808	152.8624	234796.0808	32.8624	0.0000	0.0000
105		Generator	16.50	0.00	LG	0.4	12.4568	-0.1609	0.6697	1.4969	0.7303	1.3727	13.8564	-0.0000
106	T11	Fixed-Tap Xmer	16.50	0.00	LLL	1197	41868.1960	-84.3033	41868.1959	155.6967	41868.1959	35.6967	0.0000	0.0000
107		Fixed-Tap Xmer	16.50	0.00	LG	0.0	1.4014	2.8624	0.7007	-177.1376	0.7007	-177.1376	0.0000	0.0000
108														
109	**Faulted Bus ->**													
110														
111	B39		345.00	0.00	LLL	69032	115524.4350	-87.0985	115524.4346	152.9015	115524.4346	32.9015	0.0000	0.0000
112	B39		345.00	0.00	LG	173	288.8478	1.4093	0.0000	0.0000	0.0000	0.0000	288.8478	1.4093
113														
114	**First Ring Contributions**													
115														
116	G01	Generator	345.00	0.00	LLL	66417	111148.0018	-87.1376	111148.0015	152.8624	111148.0015	32.8624	0.0000	0.0000
117		Generator	345.00	0.00	LG	168	281.4942	0.8608	4.3716	-33.5052	4.3571	-33.6315	288.7360	-0.1186
118	L15	Line	345.00	0.00	LLL	1277	2137.7635	-86.7436	2137.7634	153.2564	2137.7634	33.2564	0.0000	0.0000
119		Line	345.00	0.00	LG	2.3	3.8100	20.6798	2.1332	146.4221	2.1332	146.4221	3.7051	89.8447
120	L2	Line	345.00	0.00	LLL	1338	2239.6063	-85.4950	2239.6063	154.5050	2239.6063	34.5050	0.0000	0.0000
121		Line	345.00	0.00	LG	2.4	4.0347	22.2780	2.2311	146.4410	2.2311	146.4410	3.9963	89.7841

Global Voltage Report | Global Current Report | Global G Report | Faulted Bus -> (V) report | Faulted Bus -> (Z / IEC) report | **Faulted Bus -> (I) report**

Figure: Fault Analysis Table Showing LLL faults at buses and first ring contributions

Calculation of Circuit Breaker Parameters

Generator No	Rated Operating Voltage	Rated Symmetrical Short Circuit Current (During fault)	Maximum Symmetrical Interrupting Current	Continuous Current (Normal operation of Generators)	Rated Continuous Current	Interrupting Rating (MVA)
G01	345	111148.0018	120000	1705.5	1800	71.71
G02	16.5	154845.3746	160000	20274.6	21000	4.57
G03	16.5	213824.4829	220000	24216.0	25000	6.29
G04	16.5	204868.7873	210000	22629.2	23000	6.00
G05	16.5	73440.9349	74000	18356.1	19000	2.11
G06	16.5	175862.5191	180000	23597.6	24000	5.144
G07	16.5	147779.9466	150000	20145.3	21000	4.29
G08	16.5	163718.4720	170000	19026.4	20000	4.85
G09	16.5	234796.0816	240000	29060.2	30000	6.86
G10	16.5	220936.5499	230000	9376.7	10000	6.57

For these cases,

For all circuit breakers, k = 1 is assumed.

And Frequency of the system = 50 Hz

Tripping time delay=1 / (2*50) =0.01 s

Sample Calculation:

We consider Generator 7 for sample calculation.

For this case,

Rated Voltage = 16.5 KV

K=rated maximum voltage/ Lower limit of operation voltage =1

Rated Short-Circuit Current = 147779.9466A

So, maximum symmetrical interrupting capability = K * Rated Short-Circuit Current =147779.9466A ~ 150000A

Now, Continuous Current & Rated Continuous Current for Gen-7 is 20145.3A & 21000A

Then, Interrupting Rating= $3^{0.5}$ * 16.5*150000=4.29 MVA

Comment:

According to the data table, the Max Symmetrical Interrupting Current rating of circuit breaker for generator-5 is lowest and it is highest for generator-9. And, interrupting rating is so much high for generator-1.

We know, Max Symmetrical Interrupting Current for SF_6 Circuit breaker is between 50kA to 275kA. And all of our generators operate between this range. So, we can choose SF_6 Circuit Breaker for all generators.

Task 3

Simulation of Photovoltaic (PV) Generators

A photovoltaic (PV) generator is internally a power-limited nonlinear current source having both constant-current and constant-voltage like properties depending on the operating point. An important property of a PV generator is that even in the event of a fault or short circuit scenario, the fault current supplied by the generator is the same as the rated current of the generator.

In order to emulate synchronous generators as photovoltaic generators, we increase sub-transient value X'' (in per unit) to make fault current contribution approximately equal to corresponding rated current. Transient value X' and steady-state value X are also increased as they are supposed to be higher than sub transient value X''. We applied trial and error method and final result is given in table which is satisfactory.

Rated Current Calculation of the PV generators:

For Bus B32, Generator G3

Rated Power = 800 MVA

Rated Voltage = 16.5 kV

Rated Current = rated power / ($3^{0.5}$ *rated voltage)

= 27992.7 A

For Bus B33, Generator G4

Rated Power = 800 MVA

Rated Voltage = 16.5 kV

Rated Current = rated power / ($3^{0.5}$ *rated voltage)

= 27992.7 A

For Bus B34, Generator G4

Rated Power = 300 MVA

Rated Voltage = 16.5 kV

Rated Current = rated power / ($3^{0.5}$ *rated voltage)

= 10497.27 A

For Bus B36, Generator G7

Rated Power = 700 MVA

Rated Voltage = 16.5 kV

Rated Current = rated power / ($3^{0.5}$ *rated voltage)

= 24493.64 A

Bus	Generator (PV generator)	Rated Current (A)	Fault Current Contribution (A)	Modified Sub-transient Value, X'' (pu)
B32	G03	27992.7	27993.9355	1.94
B33	G04	27992.7	27951.7903	1.8
B34	G05	10497.27	10495.1157	12
B36	G07	24493.64	24448.2217	1.305

Power Flow Analysis:

LOAD FLOW STUDY PARAMETERS	
Study :	ModelGrid7
Time :	Sun Jul 18 22h22m08s 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]

Figure: Load flow study parameters (task 3)

COMPLETE SUMMARY REPORT

Summary Data	**Active Power**	**Reactive Power**
Total generation	**6151.593**	**1348.489**
Spinning reserve	7818.407	
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	33.967	-665.966
Transformer losses	20.525	605.556
Total losses	**54.493**	**-60.411**
Mismatches	0.000	-0.000

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

Figure: Complete summary report (task 3)

Fault Analysis:

	ID	Type	Prefault kV	Angle	Fault type	Fault S [MVA]	IL1 [A]	IL1 [deg]	IL2 [A]	IL2 [deg]
1	Faulted Bus ->									
2										
3	B32		16.50	0.00	LLL	3736	130724.5034	-87.2643	130724.5030	152.7357
4										
5	First Ring Contributions									
6										
7	G03	Generator	16.50	0.00	LLL	800	27993.9355	-87.1376	27993.9354	152.8624
8	T04	Fixed-Tap Xmer	16.50	0.00	LLL	2936	102730.6237	-87.2989	102730.6234	152.7011
9										
10	Faulted Bus ->									
11										
12	B33		16.50	0.00	LLL	3168	110841.5039	-86.4737	110841.5036	153.5263
13										
14	First Ring Contributions									
15										
16	G04	Generator	16.50	0.00	LLL	799	27951.7903	-87.1376	27951.7903	152.8624
17	T05	Fixed-Tap Xmer	16.50	0.00	LLL	2369	82892.2655	-86.2498	82892.2653	153.7502
18										

	Angle	Fault type	Fault S [MVA]	IL1 [A]	IL1 [deg]	IL2 [A]	IL2 [deg]	IL3 [A]	IL3 [deg]	In [A]	In [deg]
1											
2											
3	0.00	LLL	3736	130724.5034	-87.2643	130724.5030	152.7357	130724.5030	32.7357	0.0000	0.0000
4											
5											
6											
7	0.00	LLL	800	27993.9355	-87.1376	27993.9354	152.8624	27993.9354	32.8624	0.0000	0.0000
8	0.00	LLL	2936	102730.6237	-87.2989	102730.6234	152.7011	102730.6234	32.7011	0.0000	0.0000
9											
10											
11											
12	0.00	LLL	3168	110841.5039	-86.4737	110841.5036	153.5263	110841.5036	33.5263	0.0000	0.0000
13											
14											
15											
16	0.00	LLL	799	27951.7903	-87.1376	27951.7903	152.8624	27951.7903	32.8624	0.0000	0.0000
17	0.00	LLL	2369	82892.2655	-86.2498	82892.2653	153.7502	82892.2653	33.7502	0.0000	0.0000
18											

	ID	Type	Prefault kV	Angle	Fault type	Fault S [MVA]	IL1 [A]	IL1 [deg]	IL2 [A]	IL2 [deg]
11										
12	B33		16.50	0.00	LLL	3168	110841.5039	-86.4737	110841.5036	153.5263
13										
14	**First Ring Contributions**									
15										
16	G04	Generator	16.50	0.00	LLL	799	27951.7903	-87.1376	27951.7903	152.8624
17	T05	Fixed-Tap Xmer	16.50	0.00	LLL	2369	82892.2655	-86.2498	82892.2653	153.7502
18										
19	**Faulted Bus ->**									
20										
21	B34		16.50	0.00	LLL	2142	74947.9242	-86.6610	74947.9239	153.3390
22										
23	**First Ring Contributions**									
24										
25	G05	Generator	16.50	0.00	LLL	300	10495.1157	-87.1376	10495.1156	152.8624
26	T06	Fixed-Tap Xmer	16.50	0.00	LLL	1842	64453.2471	-86.5835	64453.2468	153.4165
27										
28	**Faulted Bus ->**									
29										
30	B36		16.50	0.00	LLL	2946	103069.2542	-87.7053	103069.2539	152.2947
31										
32	**First Ring Contributions**									
33										
34	G07	Generator	16.50	0.00	LLL	699	24448.2217	-87.1376	24448.2216	152.8624
35	T08	Fixed-Tap Xmer	16.50	0.00	LLL	2247	78622.5861	-87.8818	78622.5858	152.1182

	Angle	Fault type	Fault S [MVA]	IL1 [A]	IL1 [deg]	IL2 [A]	IL2 [deg]	IL3 [A]	IL3 [deg]	In [A]	In [deg]
11											
12	0.00	LLL	3168	110841.5039	-86.4737	110841.5036	153.5263	110841.5036	33.5263	0.0000	0.0000
13											
14											
15											
16	0.00	LLL	799	27951.7903	-87.1376	27951.7903	152.8624	27951.7903	32.8624	0.0000	0.0000
17	0.00	LLL	2369	82892.2655	-86.2498	82892.2653	153.7502	82892.2653	33.7502	0.0000	0.0000
18											
19											
20											
21	0.00	LLL	2142	74947.9242	-86.6610	74947.9239	153.3390	74947.9239	33.3390	0.0000	0.0000
22											
23											
24											
25	0.00	LLL	300	10495.1157	-87.1376	10495.1156	152.8624	10495.1156	32.8624	0.0000	0.0000
26	0.00	LLL	1842	64453.2471	-86.5835	64453.2468	153.4165	64453.2468	33.4165	0.0000	0.0000
27											
28											
29											
30	0.00	LLL	2946	103069.2542	-87.7053	103069.2539	152.2947	103069.2539	32.2947	0.0000	0.0000
31											
32											
33											
34	0.00	LLL	699	24448.2217	-87.1376	24448.2216	152.8624	24448.2216	32.8624	0.0000	0.0000
35	0.00	LLL	2247	78622.5861	-87.8818	78622.5858	152.1182	78622.5858	32.1182	0.0000	0.0000

Global Voltage Report | Global Current Report | Global G Report | Faulted Bus -> (V) report | Faulted Bus -> (Z / IEC) report | Faulted Bus -> (I) report

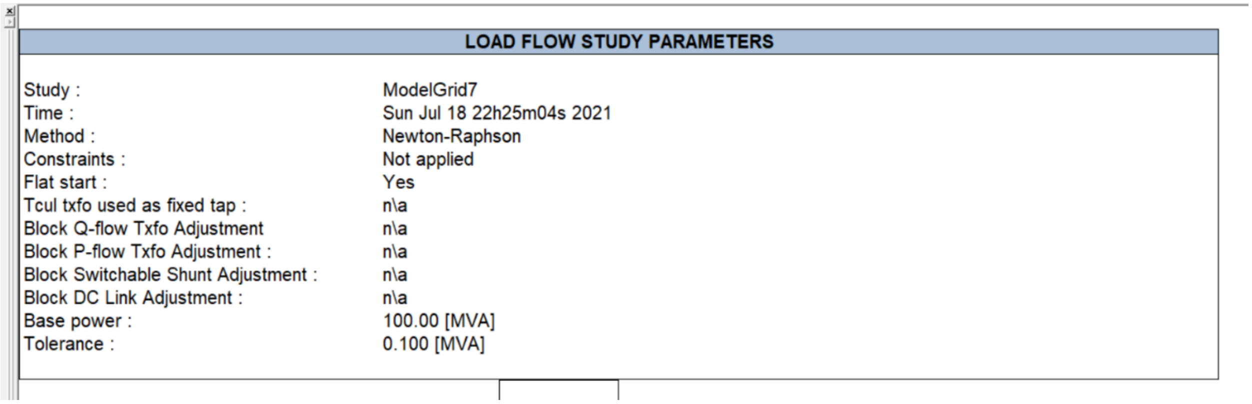
Figure: Contribution of Generator to faults for PV generators (task 3)

Task 4

Power Flow Analysis with Added Induction Motors

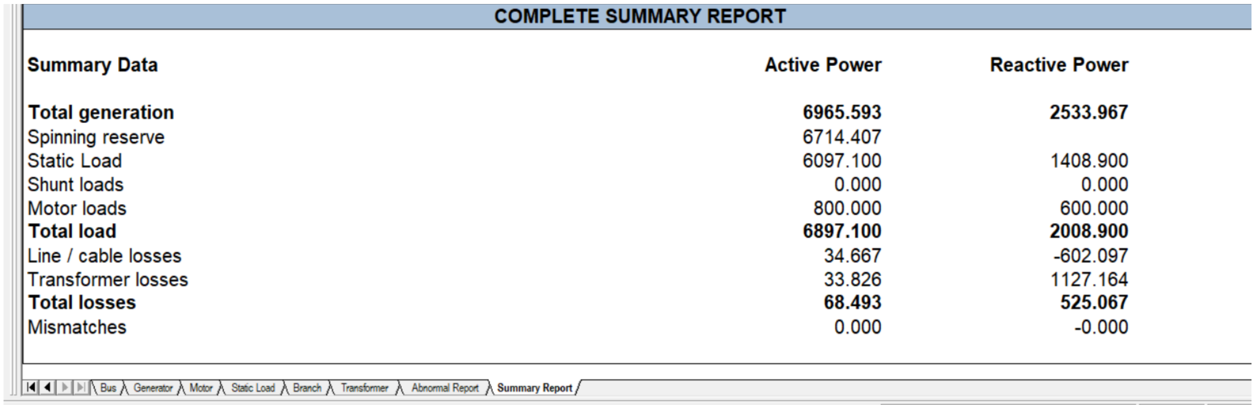
10 Induction Motors are added in Bus 23 and power flow analysis has been performed again.

Summary Report



LOAD FLOW STUDY PARAMETERS	
Study :	ModelGrid7
Time :	Sun Jul 18 22h25m04s 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]

Figure: Load flow study parameters (task 4)



COMPLETE SUMMARY REPORT

Summary Data	Active Power	Reactive Power
Total generation	**6965.593**	**2533.967**
Spinning reserve	6714.407	
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	34.667	-602.097
Transformer losses	33.826	1127.164
Total losses	**68.493**	**525.067**
Mismatches	0.000	-0.000

Figure 10: Complete summary report (task 4)

Due to the motor loads, an additional 800 MW real power and 600 MVAR reactive power is consumed by the system.

As a result, total generation, total load, overall power factor of the system and losses are impacted.

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 - [A]**	**Loading Limit - [A]**	**Emergency Loading Limit - [A]**	
8	L11	B6	B7	912.7	800.0	850.0	
9	L28	B22	B23	938.3	800.0	850.0	
10	L19	B10	B15	864.2	800.0	850.0	
11	L9	B5	B6	1337.7	1200.0	1800.0	
12							
13	***UNDERLOADED LINES & CABLES (WITHIN 50 %)***						
14	**ID**	**Bus From**	**Bus To**	**Power Flow - [A]**	**Loading Limit - [A]**		
15	L20	B15	B16	485.6	600.0		
16	L30	B25	B26	330.5	400.0		
17	L21	B16	B17	232.9	600.0		
18	L12	B6	B11	241.4	600.0		
19	L22	B16	B19	875.2	900.0		
20	L32	B26	B28	230.2	400.0		

21	L23	B16	B21	164.1	400.0	
22	L33	B26	B29	310.9	400.0	
23	L15	B9	B39	344.5	400.0	
24	L25	B17	B18	34.1	400.0	
25	L16	B10	B11	261.6	600.0	
26	L26	B17	B27	246.8	400.0	
27	L27	B21	B22	386.4	600.0	
28	L29	B23	B24	110.2	400.0	
29	L1	B1	B2	73.5	400.0	
30	L2	B1	B39	73.5	400.0	
31	L4	B2	B25	213.1	400.0	
32	L6	B3	B18	238.0	400.0	
33						
34	***OVERLOADED TRANSFORMERS (WITHIN 100 %)***					
35	**ID**	**Bus From**	**Bus To**	**Power Flow - [MVA]**	**Loading Limit - [MVA]**	**Emergency Loading Limit - [MVA]**
36	T03	B6	B31	1325.2	800.0	850.0
37						

	ID						
36	T03	B6	B31	1325.2	800.0	850.0	
37							
38	***UNDERLOADED TRANSFORMERS (WITHIN 50 %)***						
39	**ID**	**Bus From**	**Bus To**	**Power Flow - [MVA]**	**Loading Limit - [MVA]**		
40	T10	B2	B30	316.4	550.0		
41	T01	B12	B11	44.7	250.0		
42	T02	B12	B13	48.1	250.0		
43	T12	B19	B20	123.2	550.0		
44	T06	B20	B34	518.8	700.0		
45							
46	***GENERATORS AT REACTIVE LIMITS (WITHIN 0 %)***						
47	**ID**	**Bus From**	**P Gen - [MW]**	**Q Gen - [MVAR]**	**Q Min - [MVAR]**	**Q Max - [MVAR]**	
48	G06	B35	650.00	494.13	-192.00	448.00	
49	G07	B36	560.00	470.89	-168.00	392.00	
50							
51	***TRANSFORMERS AT TAP LIMITS (WITHIN 0 %)***						
52	**ID**	**Bus From**	**Bus To**	**Tap Pos - [%]**	**Min Tap - [%]**	**Max Tap - [%]**	

Bus / Generator / Motor / Static Load / Branch / Transformer / Abnormal Report / Summary Report

Figure: Abnormal report (task 4)

There are a few notable abnormalities that can be seen,

1. Some lines (11, 28, 19, 9) are overloaded
2. Transformer 3 (which is connected to the Swing generator) is overloaded.
3. Two generators (6 and 7) are outside reactive power limits.

Probable causes of the Abnormalities

Overload of Transformer 3

Due to the addition of the 10 Induction Motors, the real and reactive power consumed by the entire system has increased. However, the power supplied by the generator has not changed. As a result, the entire load of the motors is being supplied by the swing bus. Consequently, the transformer connected to the swing generator (Transformer 3) is subjected to an increased power flow which is over the rated limit of the transformer. As a result, the transformer is overloaded.

Generators 6 and 7 outside Reactive Power Limits

The additional reactive power consumed by the motors must be supplied via generators as there are no synchronous condenser or capacitor banks present in the original system. However, the total reactive power supplied by the generators is not enough to balance the total reactive power consumption of the system. Therefore, the generators are required to supply an amount of reactive power outside their limits.

Overload of Lines 11, 28, 19, 9

The introduction of a huge number of Induction Motors into the system increases the current flowing though the lines, also the inductive loads decrease the power factor which also contributes to a larger magnitude of current flowing through the system. These two effects combined, results in overloading of some of the lines.

Notably, line 28, which is connected to the Motor Bus 23. Also, the lines 9 and 11 which is connected to the overloaded transformer and swing generator.

Task 5

Solving the Abnormalities using Corrective Devices and Measures

Necessary Steps taken

1. Static VAR compensators (SVC) have been added to buses 35 and 36, to which the overloaded generators 6 and 7 are connected. SVCs are power factor correcting devices that provide reactive power to the system and balances the reactive power consumptions that the generators are unable to provide. So we can see that the reactive power limit problem, and the power factors have also been improved.
2. The induction motors operate at lagging power factor, and this causes a drop in pf in the entire system. We have used a Static VAR compensator in parallel with the Induction Motors to improve power factor in Bus 23 as well as the entire system overall.
3. The swing bus was supplying the entire load of the induction motors, causing an overload in transformer 3. We have increased the real power generation of the voltage-controlled generators to compensate the power supplied by the swing generator. This was done by trial error, as increasing active generation in only one generator causes overload in nearby lines. So, we distributed the real power generation between the generators evenly. We can see that the power flow of the transformer 3 has come down to within the limit.
4. Finally, more Static VAR compensators are used in the lines which are still overloaded (after step 3) to improve their power factor, thus lowering their current and losses and bring the line current within limits.

Modification of the Network

E:\CYME\PSAF\Database.2.81\PROJECTCOPY5.STU

	ID	Bus ID	DBase ID	Duplic	Status	Q	Ctrl'd Bus	L	Q Max	Q Min
1	SV1	B35	SV1	1	☑	3.000	B35	1.238	500.000	-200.000
2	SV2	B36	SV1	1	☑	3.000	B36	1.238	500.000	-200.000
3	SV3	B23	SV2	2	☑	3.000	B23	378.868	500.000	-500.000
4	SV4	B2	SV2	1	☑	3.000	B2	378.868	500.000	-500.000
5	SV5	B3	SV2	1	☑	3.000	B3	378.868	500.000	-500.000
6										
7										
8										
9										
10										
11										
12										
13										
14										
15										
16										
17										
18										
19										
20										
21										

Induction Motor | Static Var Compensator

Figure: Addition of Static VAR compensators (task 5)

	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	1140.000	0.000	0.00	730.000	0.100	B39	10000
2	G02	B31	G02	1	☑	Swing	0.000	0.000	0.00	730.000	0.100	B31	700
3	G03	B32	G03	1	☑	Voltage C	700.000	0.000	0.00	730.000	0.100	B32	800
4	G04	B33	G04	1	☑	Voltage C	650.000	0.000	0.00	730.000	0.100	B33	800
5	G05	B34	G05	2	☑	Voltage C	290.000	0.000	0.00	730.000	0.100	B34	300
6	G06	B35	G06	1	☑	Voltage C	750.000	0.000	0.00	730.000	0.100	B35	800
7	G07	B36	G07	1	☑	Voltage C	625.000	0.000	0.00	730.000	0.100	B36	700
8	G08	B37	G08	1	☑	Voltage C	600.000	0.000	0.00	730.000	0.100	B37	700
9	G09	B38	G09	1	☑	Voltage C	880.000	0.000	0.00	730.000	0.100	B38	1000
10	G10	B30	G10	1	☑	Voltage C	275.000	0.000	0.00	730.000	0.100	B30	1000
11													
12													
13													
14													
15													
16													
17													
18													
19													
20													

Induction Motor | Static Var Compensator | Generator

Figure: Increase of Generator's Real power generation (task 5)

After taking all these measures, all the abnormalities of the system have been resolved.

<u>Summary Report</u>

COMPLETE SUMMARY REPORT		
Summary Data	**Active Power**	**Reactive Power**
Total generation	**6955.514**	**2125.657**
Spinning reserve	6724.486	
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	32.130	-686.211
Transformer losses	26.284	802.969
Total losses	**58.414**	**116.758**
Mismatches	0.000	-0.001

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

Figure: Complete summary report (task 5)

LOAD FLOW STUDY PARAMETERS	
Study :	ModelGrid7
Time :	Wed Jul 21 17h43m24s 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]

Figure: Load flow study parameters (task 5)

<u>Abnormal Report</u>

	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 - [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	L20	B15	B16	347.7	600.0		
12	L21	B16	B17	138.3	600.0		
13	L12	B6	B11	305.1	600.0		
14	L32	B26	B28	269.6	400.0		
15	L23	B16	B21	84.0	400.0		
16	L33	B26	B29	350.2	400.0		
17	L14	B7	B9	325.2	400.0		
18	L15	B9	B39	268.4	400.0		
19	L25	B17	B18	176.1	400.0		
20	L16	B10	B11	328.5	600.0		
21	L26	B17	B27	230.5	400.0		
22	L27	B21	B22	533.0	600.0		
23	L29	B23	B24	63.3	400.0		
24	L1	B1	B2	88.6	400.0		
25	L2	B1	B39	88.6	400.0		
26	L4	B2	B25	325.2	400.0		
27	L5	B3	B4	345.6	400.0		
28	L6	B3	B18	119.7	400.0		
29	L7	B4	B5	397.2	400.0		
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	B2	B30	369.3	550.0		
37	T01	B12	B11	43.1	250.0		
38	T02	B12	B13	45.5	250.0		
39	T12	B19	B20	53.3	550.0		
40	T06	B20	B34	583.6	700.0		
41							
42	***GENERATORS AT REACTIVE LIMITS (WITHIN 0 %)***						
43	**ID**	**Bus From**	**P Gen - [MW]**	**Q Gen - [MVAR]**	**Q Min - [MVAR]**	**Q Max - [MVAR]**	
44							
45	***TRANSFORMERS AT TAP LIMITS (WITHIN 0 %)***						
46	**ID**	**Bus From**	**Bus To**	**Tap Pos - [%]**	**Min Tap - [%]**	**Max Tap - [%]**	

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

Figure: Abnormal report (task 5)

Conclusion:

Simulation and Study of High Voltage DC (HVDC) System and Photovoltaic (PV) Generators is of vital importance is the near future as the power generation continues its gradual shift towards Solar Power and long-distance DC transmissions. Also, it is important for electrical engineers to be able to abnormalities that can arise in a power system as loads continuously change and adapt the system accordingly to avoid any undesirable scenarios and keep the power system from running smoothly. In this project, we also managed to understand the relationship between industrial loads and the generators, as well as how the power transfer devices like transformers behave in sync with the generators. Also, we are able to determine the circuit breakers required in the system to improve overall system stability and safety.