APPENDIX-I : BUS DATA FOR IEEE-14 BUS SYSTEM

Bus No	Bus Code	Voltage Magnitude	Angle Degrees	Load		Generator				Injected MVAR
				MW	MVAR	MW	MVAR	Qmin	Qmax	
1	1	1.06	0	30.38	17.78	40	-40	0	0	0
2	2	1.045	0	0	0	232	0	-40	50	0
3	2	1.01	0	131.88	26.6	0	0	0	40	0
4	0	1	0	66.92	10	0	0	0	0	0
5	0	1	0	10.64	2.24	0	0	0	0	0
6	2	1.07	0	15.68	10.5	0	0	-6	24	0
7	0	1	0	0	0	0	0	0	0	0
8	2	1.09	0	0	0	0	0	-6	24	0
9	0	1	0	41.3	23.24	0	0	0	0	0
10	0	1	0	12.6	8.12	0	0	0	0	0
11	0	1	0	4.9	2.52	0	0	0	0	0
12	0	1	0	8.54	2.24	0	0	0	0	0
13	0	1	0	18.9	8.12	0	0	0	0	0
14	0	1	0	20.86	7	0	0	0	0	0

APPENDIX-II : LINE DATA FOR IEEE-14 BUS SYSTEM

Sendind end Bus	Receiving end Bus	Resistance p.u.	Reactance p.u.	Half Susceptance p.u.	Tranformer tap
1	2	0.01938	0.05917	0.0264	1
2	3	0.04699	0.19797	0.0219	1
2	4	0.05811	0.17632	0.0187	1
1	5	0.05403	0.22304	0.0246	1
2	5	0.05695	0.17388	0.017	1
3	4	0.06701	0.17103	0.0173	1
4	5	0.01335	0.04211	0.0064	1
5	6	0	0.25202	0	0.932
4	7	0	0.20912	0	0.978
7	8	0	0.17615	0	1
4	9	0	0.55618	0	0.969
7	9	0	0.11001	0	1
9	10	0.03181	0.0845	0	1
6	11	0.09498	0.1989	0	1
6	12	0.12291	0.25581	0	1
6	13	0.06615	0.13027	0	1
9	14	0.12711	0.27038	0	1
10	11	0.08205	0.19207	0	1
12	13	0.22092	0.19988	0	1
13	14	0.17093	0.34802	0	1

APPENDIX-III : BUS DATA FOR 13-BUS ILL-CONDITIONED SYSTEM

Bus No	Bus Code	Voltage Magnitude	Angle Degrees	Load		Generator				Injected MVAR
				MW	MVAR	MW	MVAR	Qmin	Qmax	
1	1	1	0	1650	560	0	0	0	0	0
2	0	1	0	0	0	0	0	0	0	0
3	0	1	0	0	0	0	0	0	0	0
4	0	1	0	0	0	0	0	0	0	0
5	2	1	0	0	0	0	0	-500	0	0
6	2	1.037	0	50	30	500	0	-250	0	0
7	0	1.063	0	0	0	0	0	0	0	0
8	2	1.1	0	0	0	0	0	-100	500	0
9	2	0.943	0	0	0	500	0	-1000	0	0
10	2	1.1	0	50	0	50	0	-50	0	0
11	0	1	0	50	30	0	0	0	0	0
12	0	1	0	50	32	0	0	0	0	0
13	0	1	0	0	0	0	0	0	0	0

APPENDIX-IV : LINE DATA FOR 13-BUS ILL-CONDITIONED SYSTEM

Sendind end Bus	Receiving end Bus	Resistance p.u.	Reactance p.u.	Half Susceptance p.u.	Tranformer tap
1	2	0.004	0.085	0	1
1	3	0.004	0.0947	0	1
5	4	0.004	0.0947	0	1
4	3	0.0074	0.143	0.109	1
6	2	0.0481	0.459	0.0615	1
6	7	0.009	0.108	0.004	1
8	3	0.0121	0.233	0.178	1
7	8	0	0.15	0	1
9	10	0.0105	0.202	0.155	1
10	11	0	-0.15	0	1
11	12	0.0086	0.1665	0.127	1
12	13	0.0075	0.1465	0.112	1
13	8	0	-0.15	0	1

APPENDIX-V : BUS DATA FOR 11-BUS ILL-CONDITIONED SYSTEM

Bus No	Bus Code	Voltage Magnitude	Angle Degrees	Load		Generator				Injected MVAR
				MW	MVAR	MW	MVAR	Qmin	Qmax	
1	1	1.024	0	0	0	0	0	0	0	0
2	2	1	0	0	0	0	0	-1	1	0
3	0	1	0	12.8	6.2	0	0	0	0	0
4	2	1	0	0	0	0	0	-1	1	0
5	0	1	0	16.5	8	0	0	0	0	0
6	0	1	0	9	6.8	0	0	0	0	0
7	2	1	0	0	0	0	0	-1	1	0
8	2	1	0	0	0	0	0	-1	1	0
9	0	1	0	2.6	0.9	0	0	0	0	0
10	2	1	0	0	0	0	0	-1	1	0
11	0	1	0	15.8	5.7	0	0	0	0	0

APPENDIX-VI : LINE DATA FOR 11-BUS ILL-CONDITIONED SYSTEM

Sendind end Bus	Receiving end Bus	Resistance p.u.	Reactance p.u.	Half Susceptance p.u.	Tranformer tap
1	2	0	0.0706	0	1
2	3	0	0.154	0	1
2	4	0.0377	0.0413	0	1
3	5	0.1228	0.1803	0	1
4	5	0	0.4593	0	1
4	6	0	0.0176	0	1
4	7	0.6114	0.8117	0	1
7	8	0.6209	0.2167	0	1
8	9	0.0718	0.7179	0	1
8	10	0.4097	0.56	0	1
10	11	0.0264	0.2646	0	1

APPENDIX-VII: SINGLE LINE DIAGRAM OF IEEE-14 BUS SYSTEM

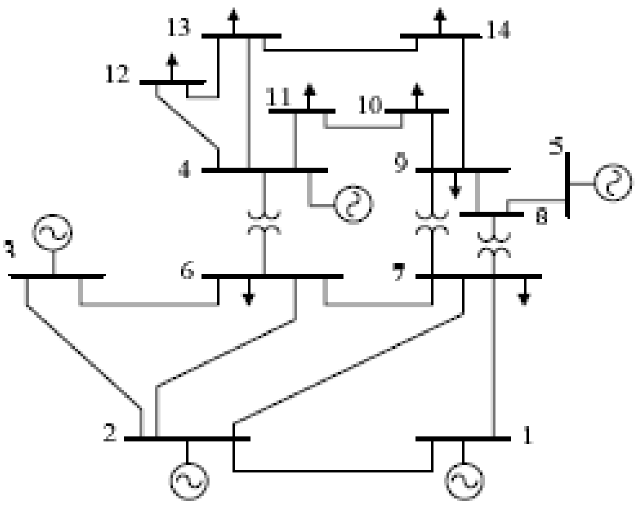

Figure: IEEE 14 Bus test system

APPENDIX-VIII SINGLE LINE DIAGRAM OF 13-BUS ILL-CONDITIONED SYSTEM

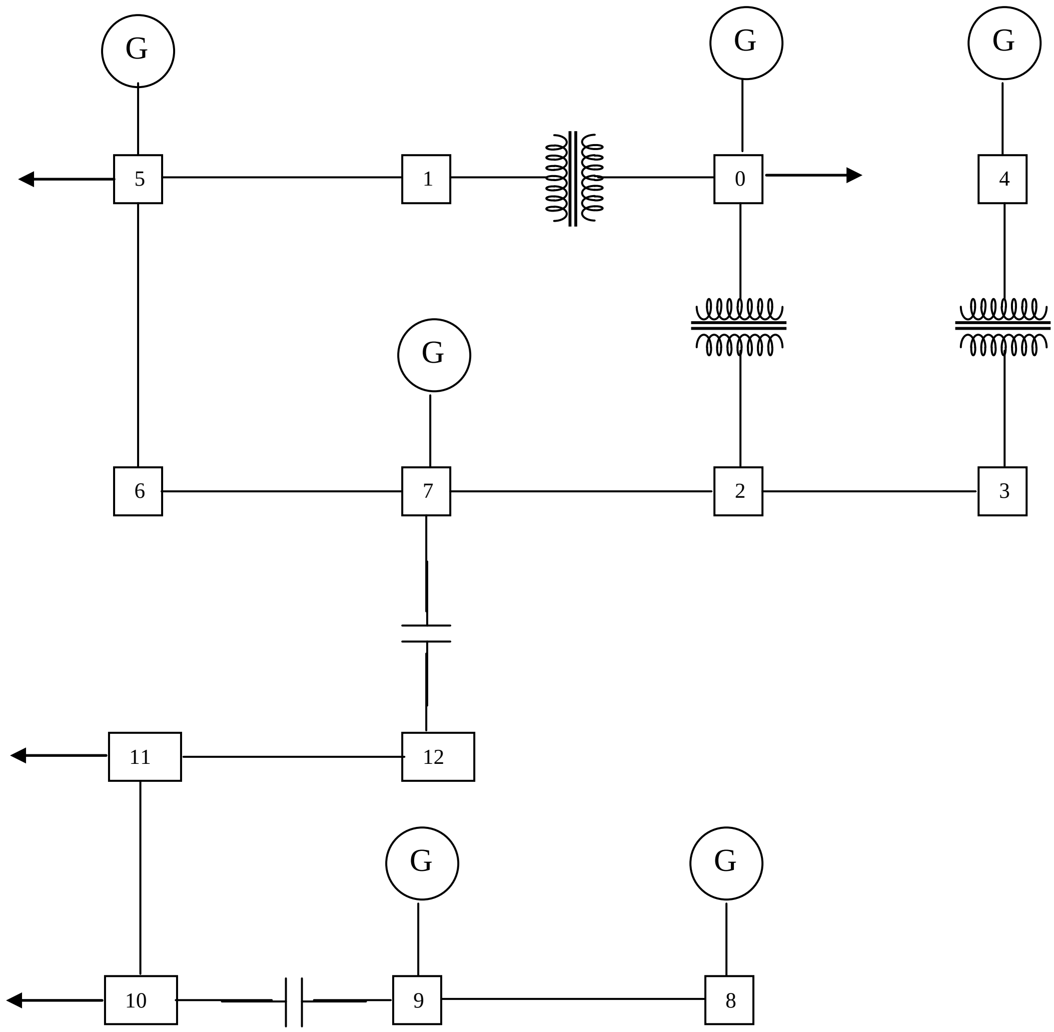

Figure: 13 Bus ill-conditioned power system

APPENDIX-IX SINGLE LINE DIAGRAM OF 11-BUS ILL-CONDITIONED SYSTEM

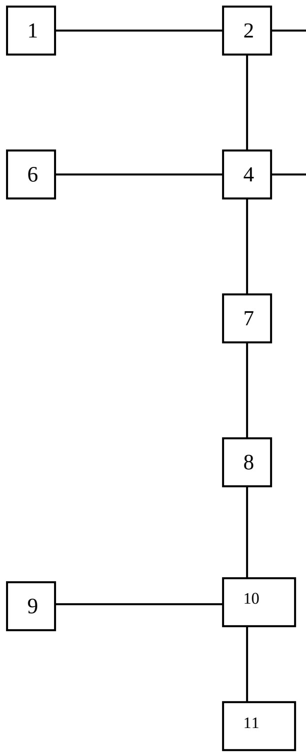

Figure: 11 Bus ill-conditioned power system

APPENDIX-X: CLARIFICATIONS TO QUERIES

4Q1:

The prescribed range of R/X ratio for a transmission line is 0 to 1. The resistance part of every line for IEEE-14 bus test system is increased by 4 times in steps of 0.5 times to create ill conditionality and to check for convergence with and without the incorporation of FACTS devices. The observations made in this study,

The R/X ratio is with in the prescribed range when the line resistance is increased by 2.5 times the base case. Further increase in the line resistance has crossed the prescribed range and when the line resistance is increased beyond 4 times, the test system has diverged. This observation is same even with the incorporation of FACTS devices.

The transmission line connected between buses 12 and 13 has an R/X ratio of 1.10526 which is beyond the prescribed range.

4Q2

The effect of varying resistance from 1 to 4 times the original case on the load flow solution results in increased no. of iterations and also there is increase in maximum power mismatch. The no. of sets considered for this study is to observe the point of divergence and ill conditionality.

4Q3

Based on the R/X ratio, FACTS devices are inserted. The line having highest R/X ratio is given first priority. Incase of divergence, the line having next highest R/X ratio is considered for locating FACTS devices. The lines with high R/X ratio is considered to incorporate the series device TCSC and combined series-shunt device UPFC because lines which have high R/X ratio are tend to diverge as discussed by many researchers. The shunt devices like SVC and STATCOM are connected to buses to check the operating capability of injecting and absorbing MVARs. Hence, the location of these devices is not fixed to a particular bus. Thus, trail and error method is followed and optimal locations are found which provides better convergence characteristics.

4Q4

FACTS controllers incorporated into the test system for power flow analysis results in highly nonlinear equations which should be suitably initialized to ensure quadratic convergent solutions when using the Newton–Raphson method. This section addresses simple and effective initialization procedures for all FACTS models in power flow studies carried out in this thesis.

1. Controllers Represented by Shunt Synchronous Voltage Source

Extensive use of FACTS models represented by shunt voltage sources indicates that elements such as the STATCOM, the shunt source of the UPFC are suitably initialized by selecting 1 p.u. voltage magnitudes and 0^o phase angles.

2. Controllers Represented by Shunt Admittance

It has been found that the SVC is well initialized by selecting a firing-angle value that corresponds to the reactance resonant peak.

3. Controllers Represented by Series Reactance

The TCSC can be represented as an equivalent variable reactance, the ability of which either to generate or to absorb reactive power is a function of the thyristor firing angle. The adjustable reactance representing the TCSC module shown in Figure 3.6 is well described by Equations (3.17)–(3.21).

Normally, the active power flow through the TCSC is chosen to be the control variable, and firing angle is chosen to be the state variable. Hence, good initial values for firing angle become mandatory in order to ensure robust iterative solutions. To this end, an approximation of Equation (5.31) is used:

$$\alpha_{TCSC} = \pi - \frac{1}{\varpi}\arctan(\frac{-X_{TL}}{C_2\varpi})$$

4. Controllers Represented by UPFC

Suitable initialization of series voltage sources in power flow studies is mandatory to ensure robust solutions. Different equations exist for the purpose of initializing the series voltage source, depending on the operating condition exhibited by the controller. For example, for the case when active and reactive powers are specified at bus k, and assuming $V_k=V_m=1$ p.u., and $\theta_k=\theta_m=0$ in equations (3.34a) and (3.34b), leads to the following simple expressions:

$$V_{cR} = X_{cR}(P_{m,sp}^2 + Q_{m,sp}^2)^{1/2}$$

$$\theta_{cR} = \arctan\left(\frac{P_{m,sp}}{Q_{m,sp}}\right)$$

These equations are used to initialize the parameters of series voltage sources within the Newton–Raphson power flow solution. These parameters are referred to as V_{vR} and θ_{vR}.

4Q5

The power flow algorithm with incorporation of some of FACTS devices like TCSC and UPFC is developed based on the assumption that a virtual bus is created in the line where FACTS device is inserted. Hence, the no. of buses of the test system will be increased by no. of FACTS devices connected in the system. In this study, IEEE -14 bus test system is incorporated with only one device. Hence, the results shown in Tables 4.27 to 4.48 represent 15 buses.

5Q2

The figures 5.2 to 5.9 show the overview of the results with the 4 methods taken with two test systems with and without FACTS controllers. For all the methods, the devices such as TCSC and UPFC have taken more no. of iterations to converge for both the test systems considered. Where as the shunt connected devices like SVC, STATCOM have taken less number of iterations to converge for both the test systems considered.

The maximum power mismatch for TCSC and UPFC is higher during the first few iterations and the mismatch reduces as the no. of iterations progressed. Finally, the mismatch is with in the tolerance range when the load flow solution has converged.