VOLTAGE STABILITY IMPROVEMENT IN POWER SYSTEM BY USING STATCOM

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Abstract :

Voltage stability problems usually occur in heavily loaded systems. Nowadays the power demand increases enormously, hence in a large interconnected power system network subject to stress conditions. This situation can be handled by increasing the generation or reducing the transmission losses. When the load increases suddenly, voltage magnitude also varies beyond the permissible voltage stability limit. But the voltage magnitude must be maintained within the limit for proper operation of the system. Hence, voltage stability must be improved by providing suitable reactive power compensation. The proposed work was analyzed using IEEE 14 bus test system. The STATCOM improves the voltage stability margin of the system.

Keywords: Voltage stability, Continuation power flow, STATCOM, PV Curve

1. Introduction

Power system stability is defined as the ability of a power system that enables it to remain in stable operating equilibrium under normal operating conditions and to regain an acceptable state of equilibrium after being subjected to a disturbance [1]. A criterion for voltage stability is that, at a given operating condition for every bus in the system, the bus voltage magnitude increases as the reactive power injection in the same bus is increased. The power system voltage is stable if voltages after disturbances are close to voltages at normal operating conditions. A power system becomes unstable when voltages uncontrollably decrease due to outage of equipment, sudden increment in load. Voltage stability is generally a local problem, but the consequences of voltage instability have significant impact on the power system. The result of this impact is voltage collapse and a blackout. The voltage stability of the system mainly depends on generator reactive power limits, load characteristics, transmission lines. For efficient and reliable operation of power system, the voltage and reactive power control must be properly done to make voltage at all the buses within the acceptable limits [2,3]. Voltage stability has been the major reason for several major blackouts that have occurred throughout the world including the recently Northeast Power outage in North America in August 2003 [4].

As the load varies, the reactive power requirements of the transmission system also vary. Since the reactive power cannot be transferred over long distances and losses also increases. It is important that voltage control has to be done by locating proper compensating devices. The proper selection and location of compensator for controlling reactive power and voltage are major challenges of power system. In this paper, we are proposed to identify the suitable location for compensator to improve the voltage stability in the power system not only in normal loading condition and also in maximum loading condition.

2. Static Voltage Stability

In static voltage stability, slowly developing changes in the power system occur that eventually lead to a shortage of reactive power and declining voltage. Voltage collapse phenomena in power systems have become one of the important concerns of the power industry. V. Ajjarapu and C. Christy in [5] proposed the continuation power flow method for voltage stability studies. Online Voltage Stability monitoring using VAR reserves is given in [6]. Static Voltage stability analysis using fuzzy set approach is proposed in [8]. Point of collapse method and continuation method are used for voltage collapse studies [9]. Saddle-Node Bifurcation theory is used to analysis the voltage stability is discussed in [10]. In [11] proposed approach is based on TCSC comparison with STATCOM compensation to increase the steady state voltage stability margin of power capability.

The continuation power flow method is used for voltage stability analysis. The only way to save the system from voltage collapse is to reduce the reactive power load or add additional reactive power prior to reaching the point of voltage collapse .Usually; placing adequate reactive power support at the “weakest bus” enhances static-voltage stability margins.

3. Voltage stability improvement and control

Reactive power compensation is the most effective method to improve both voltage stability and power transfer capability of the system. The control of voltage bus level is accomplished by controlling the generation, absorption and flow of reactive power. Voltage stability and loadability of a bus in the power system is mainly depends on the reactive power support that the bus can receive. When the system approaches the Maximum Loading Point then the real and reactive power losses are increasing rapidly. Therefore, the sufficient reactive power supports have to be given to maintain the voltage stability.

4. Static Synchronous Compensator (STATCOM)

STATCOM is the Voltage-Source Inverter, which converts a DC input voltage into AC output voltage in order to compensate the active and reactive power needed by the system. The modeling STATCOM is demonstrated in [7]. Figure.1 shows the Basic structure and Figure.2 shows the typical steady state V–I characteristic of STATCOM. STATCOM is a shunt-connected device, which controls the voltage at the connected base to the reference value by adjusting voltage and angle of internal voltage source. STATCOM exhibits constant current characteristics when the voltage is low/high under/over the limit. This allows STATCOM to deliver constant reactive power to the system.

Reactive power absorbed or supplied by STATCOM is automatically adjusted so as to maintain voltages of the buses to which they are connected. The advantages of STATCOM are small size, lower costs and flexible regulation from capacitive range to inductive range. The STATCOM can be operated over its full output current range even at very low voltage. The maximum capacitive or inductive output current of the STATCOM can be maintained independently of the AC system voltage.

Figure 1. Basic structure of STACOM

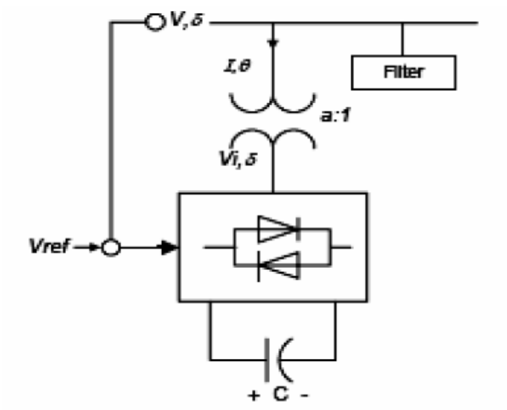
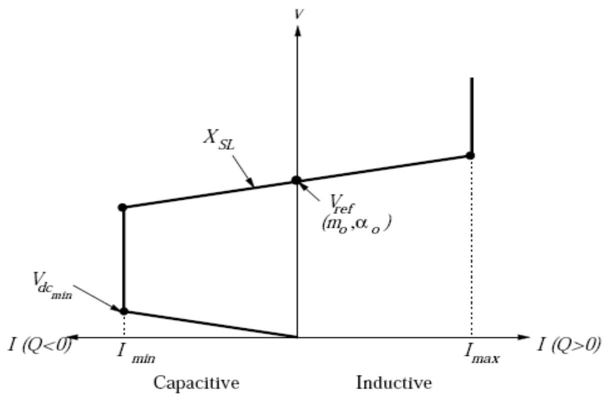


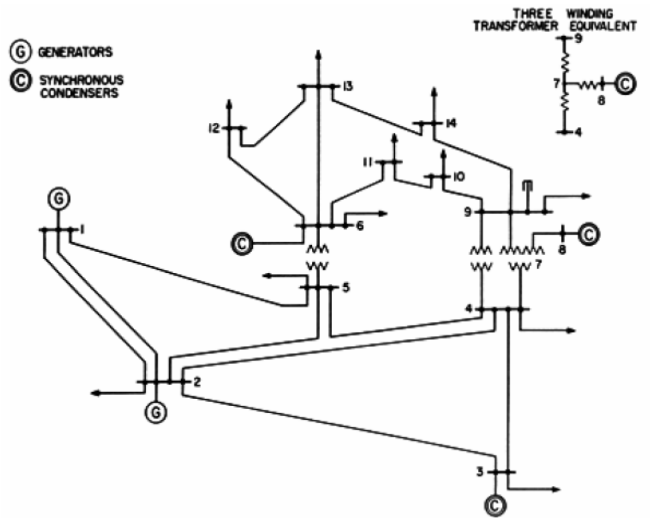
Figure 2. Typical steady state V–I characteristic of a STATCOM



5. Simulation Results

The IEEE 14-bus test system as shown in figure.3 is used for voltage stability studies. The test system consists of 5 generator buses and 11 load buses. The behavior of the test system with and without STATCOM under different loading conditions is studied. The location of the STATCOM is determined by identifying weakest bus in the system.

Figure 3. IEEE 14-bus test system



The test system is analyzed under normal and maximum loading condition. The result shows that STATCOM improves the voltage stability and reduces the real power losses in the system.

Case 1. Under normal loading condition

In case 1. The test system is analysis under normal loading condition using Newton Raphson load flow method with and without STATCOM.

Table 1.Bus voltages without STATCOM under normal loading condition

Bus No.	Without STATCOM	
	Voltage Magnitude (p.u)	Angle (deg.)
1	1.0600	0
2	1.0450	-7.7663
3	1.0100	-18.9992
4	0.9977	-15.0953
5	1.0024	-13.0337
6	1.0700	-21.7463
7	1.0347	-20.2771
8	1.0900	-20.2771
9	1.0111	-23.0248
10	1.0105	-23.2008
11	1.0346	-22.6341
12	1.0461	-23.0009
13	1.0362	-23.1010
14	0.9957	-24.5526

Table 2. Bus voltages with STATCOM under normal loading condition

Bus No.	With STATCOM	
	Voltage Magnitude (p.u)	Angle (deg.)
1	1.0600	0
2	1.0450	-4.9879
3	1.0100	-12.7510
4	1.0130	-10.2406
5	1.0167	-8.7507
6	1.0700	-14.3511
7	1.0525	-13.2585
8	1.0900	-13.2585
9	1.0390	-14.8406
10	1.0369	-15.0369
11	1.0497	-14.8152
12	1.0558	-15.2299
13	1.0514	-15.3475
14	1.0400	-16.4231

Table 3. Line flows and losses without STATCOM under normal loading condition

Line No.	Line flows without STATCOM						Losses without STATCOM	
	Buses	P flow (p.u)	Q flow (p.u)	Buses	P flow (p.u)	Q flow (p.u)	P loss (p.u)	Q loss (p.u)
1	2-5	0.58278	0.07227	5-2	-0.5646	-0.0525	0.01814	0.01975
2	6-12	0.11726	0.04464	12-6	-0.1156	-0.0411	0.00169	0.00352
3	12-13	0.03017	0.01873	13-12	-0.0299	-0.0185	0.00025	0.00023
4	6-13	0.27313	0.14163	13-6	-0.2677	-0.1309	0.00547	0.01077
5	6-11	0.14449	0.12199	11-6	-0.1415	-0.1158	0.00297	0.00621
6	11-10	0.09253	0.09057	10-11	-0.0912	-0.0876	0.00129	0.00301
7	9-10	0.03480	-0.00626	10-9	-0.0348	0.0064	0.00004	0.00010
8	9-14	0.10400	0.01006	14-9	-0.1026	-0.0072	0.00136	0.00289
9	14-13	-0.10596	-0.06283	13-14	0.1086	0.0682	0.00262	0.00533
10	7-9	0.45586	0.23268	9-7	-0.4559	-0.2058	0.00000	0.02692
11	1-2	2.41497	-0.38021	2-1	-2.3123	0.6353	0.10271	0.25510
12	3-2	-1.00031	0.13866	2-3	1.0476	0.0143	0.04729	0.15297
13	3-4	-0.31849	0.19330	4-3	0.3281	-0.2037	0.00959	-0.01040
14	1-5	1.10555	0.10122	5-1	-1.0460	0.0923	0.05957	0.19356
15	5-4	0.81253	-0.13835	4-5	-0.8035	0.1539	0.00900	0.01560
16	2-4	0.77808	0.05165	4-2	-0.7456	0.0079	0.03249	0.05955
17	4-9	0.09598	0.03594	9-4	-0.0959	-0.0304	0.00005	0.00551
18	5-6	0.69168	0.07613	6-5	-0.6917	0.0294	0	0.10550
19	4-7	0.45586	-0.05009	7-4	-0.4559	0.0923	0	0.04226
20	8-7	0	0.34242	7-8	0	-0.3250	0	0.01738
						Total losses	0.2945	0.9158

Table : 4 Line flows and losses with STATCOM under normal loading condition

Line No.	Line flows with STATCOM						Losses with STATCOM	
	Buses	P flow (p.u)	Q flow (p.u)	Buses	P flow (p.u)	Q flow (p.u)	P loss (p.u)	Q loss (p.u)
1	2-5	0.4164	0.0285	5-2	-0.4073	-0.0367	0.0092	-0.0082
2	6-12	0.0785	0.0223	12-6	-0.0777	-0.0208	0.0007	0.0015
3	12-13	0.0167	0.0048	13-12	-0.0167	-0.0048	0.0001	0.0001
4	6-13	0.1817	0.0622	13-6	-0.1796	-0.0580	0.0021	0.0042
5	6-11	0.0798	0.0712	11-6	-0.0788	-0.0692	0.0009	0.0020
6	11-10	0.0438	0.0512	10-11	-0.0435	-0.0504	0.0003	0.0008
7	9-10	0.0466	0.0077	10-9	-0.0465	-0.0076	0.0001	0.0002
8	9-14	0.0895	-0.0445	14-9	-0.0883	0.0470	0.0012	0.0025
9	14-13	-0.0607	-0.0036	13-14	0.0613	0.0047	0.0006	0.0012
10	7-9	0.2744	0.1329	9-7	-0.2744	-0.1236	0.0000	0.0092
11	1-2	1.5704	-0.2044	2-1	-1.5274	0.2774	0.0431	0.0730
12	3-2	-0.7109	0.0167	2-3	0.7342	0.0354	0.0233	0.0521
13	3-4	-0.2311	0.0612	4-3	0.2350	-0.0866	0.0039	-0.0254
14	1-5	0.7543	0.0518	5-1	-0.7267	0.0093	0.0277	0.0611
15	5-4	0.6059	-0.1009	4-5	-0.6011	0.1030	0.0049	0.0021
16	2-4	0.5597	0.0103	4-2	-0.5430	0.0009	0.0167	0.0111
17	4-9	0.4520	0.1123	9-4	-0.4520	-0.0664	0	0.0459
18	5-6	0.1566	0.0183	6-5	-0.1566	-0.0056	0	0.0127
19	4-7	0.2744	-0.0756	7-4	-0.2744	0.0914	0	0.0158
20	8-7	0	0.2323	7-8	0	-0.2243	0	0.0080
						Total losses	0.1348	0.2699

Table 1. Shows the bus voltages without STATCOM under normal loading condition, it is observed from the above table, the bus 14 has the lowest voltage magnitude and it is identified weakest bus among the all other buses. The voltage magnitude at bus 14 is of 0.9957 p.u. Table 3. Shows the line flows and losses in the system without STATCOM under normal loading condition, it is absorbed that the total real power loss is 0.2945 p.u and reactive power loss is 0.9158 p.u.This losses also need to be reduced by providing proper compensation.
Table 2. Shows the bus voltage with STATCOM under normal loading condition, from the result, it is clear that the bus voltage magnitude is improved by inserting STATCOM at bus 14. After inserting STATCOM voltage magnitude at bus 14 is becomes 1.0400 p.u. Table 4. Shows the line flows and losses in the system with STATCOM under normal loading condition, it is absorbed from the result that the total real power loss is 0.1348 p.u and reactive power loss is 0.2699 p.u

By comparison of table.1 and table.2 Bus voltage magnitude is slightly improved by inserting STATCOM at bus 14 and real power loss is reduced from 0.2945 p.u to 0.1348 p.u and reactive power loss is also reduced from 0.9158 p.u to 0.2699 p.u

Case 2. Under maximum loading condition

In case 2. The test system is analysis under maximum loading condition using continuation power flow methods with and without STATCOM.

Table 5. Bus voltages without STATCOM under maximum loading condition

Bus No.	Without STATCOM	
	Voltage Magnitude (p.u)	Angle (deg.)
1	1.0600	0
2	1.0450	-37.6422
3	1.0100	-87.5802
4	0.6929	-72.2103
5	0.6753	-61.6821
6	1.0700	-108.5309
7	0.7914	-96.1764
8	1.0900	-96.1764
9	0.6973	-108.7165
10	0.7207	-110.6837
11	0.8751	-109.9558
12	0.9763	-112.5078
13	0.9259	-112.5610
14	0.6815	-118.5709

Table 6. Bus voltages with STATCOM under maximum loading condition

Bus No.	With STATCOM	
	Voltage Magnitude (p.u)	Angle (deg.)
1	1.0600	0.0000
2	1.0450	-28.1300
3	1.0100	-68.8650
4	0.8047	-55.1767
5	0.8032	-47.1345
6	1.0700	-79.7820
7	0.8812	-71.9821
8	1.0900	-71.9821
9	0.8097	-80.8741
10	0.8198	-82.1942
11	0.9274	-81.3535
12	0.9952	-83.4360
13	0.9609	-83.7091
14	0.8150	-88.9637

Table 7. Line flows and losses without STATCOM under maximum loading condition

Line No.	Line flows without STATCOM						Losses without STATCOM	
	Buses	P flow (p.u)	Q flow (p.u)	Buses	P flow (p.u)	Q flow (p.u)	P loss (p.u)	Q loss (p.u)
1	2-5	2.2545	1.8168	5-2	-1.8138	-0.4974	0.4407	1.3193
2	6-12	0.3870	0.2159	12-6	-0.3659	-0.1720	0.0211	0.0439
3	12-13	0.1243	0.1087	13-12	-0.1180	-0.1030	0.0063	0.0057
4	6-13	0.9103	0.7402	13-6	-0.8308	-0.5835	0.0795	0.1566
5	6-11	0.5036	0.8094	11-6	-0.4282	-0.6516	0.0754	0.1579
6	11-10	0.2896	0.5803	10-11	-0.2445	-0.4748	0.0451	0.1055
7	9-10	0.1163	-0.2333	10-9	-0.1119	0.2451	0.0044	0.0118
8	9-14	0.2720	-0.0612	14-9	-0.2517	0.1045	0.0203	0.0432
9	14-13	-0.3384	-0.3025	13-14	0.4142	0.4568	0.0758	0.1544
10	7-9	1.0891	0.7967	9-7	-1.0891	-0.4769	0.0000	0.3198
11	1-2	11.5577	0.3504	2-1	-9.2512	6.6332	2.3065	6.9836
12	3-2	-3.4759	2.5242	2-3	4.3312	1.0328	0.8553	3.5570
13	3-4	-0.2544	2.1010	4-3	0.5535	-1.3635	0.2991	0.7375
14	1-5	3.4731	2.6462	5-1	-2.5493	1.1286	0.9238	3.7748
15	5-4	1.8177	-0.6738	4-5	-1.7078	1.0145	0.1099	0.3406
16	2-4	2.9376	1.8233	4-2	-2.2975	0.0895	0.6401	1.9128
17	4-9	0.4698	0.1508	9-4	-0.4674	0.1140	0.0024	0.2648
18	5-6	2.2444	-0.0207	6-5	-2.2444	2.4388	0	2.4181
19	4-7	1.0891	-0.0497	7-4	-1.0891	0.5449	0	0.4952
20	8-7	0	1.8478	7-8	0	-1.3416	0	0.5062
						Total losses	5.9058	23.3089

Table 8. Line flows and losses with STATCOM under maximum loading condition

Line No.	Line flows with STATCOM						Losses with STATCOM	
	Buses	P flow (p.u)	Q flow (p.u)	Buses	P flow (p.u)	Q flow (p.u)	P loss (p.u)	Q loss (p.u)
1	2-5	1.9273	1.0666	5-2	-1.6722	-0.3172	0.2551	0.7494
2	6-12	0.3410	0.1576	12-6	-0.3258	-0.1260	0.0151	0.0315
3	12-13	0.0953	0.0656	13-12	-0.0923	-0.0629	0.0030	0.0027
4	6-13	0.7990	0.5091	13-6	-0.7472	-0.4070	0.0519	0.1021
5	6-11	0.4104	0.5730	11-6	-0.3692	-0.4867	0.0412	0.0863
6	11-10	0.2369	0.4187	10-11	-0.2148	-0.3670	0.0221	0.0517
7	9-10	0.1271	-0.1430	10-9	-0.1254	0.1477	0.0018	0.0047
8	9-14	0.2845	-0.1254	14-9	-0.2658	0.1652	0.0187	0.0399
9	14-13	-0.2975	-0.1861	13-14	0.3292	0.2506	0.0317	0.0645
10	7-9	1.0025	0.6507	9-7	-1.0025	-0.4484	0.0000	0.2024
11	1-2	8.7048	-0.4007	2-1	-7.3954	4.3398	1.3093	3.9390
12	3-2	-3.0434	1.8131	2-3	3.6252	0.5920	0.5818	2.4050
13	3-4	-0.5174	1.5321	4-3	0.6927	-1.1134	0.1754	0.4187
14	1-5	3.2012	1.6379	5-1	-2.5750	0.9035	0.6262	2.5413
15	5-4	1.9861	-0.5128	4-5	-1.8991	0.7790	0.0870	0.2661
16	2-4	2.5347	1.0897	4-2	-2.1272	0.1140	0.4074	1.2038
17	4-9	1.9738	-0.1339	9-4	-1.9738	1.4621	0.0000	1.3282
18	5-6	0.5243	0.1507	6-5	-0.5243	0.0893	0.0000	0.2399
19	4-7	1.0025	-0.0814	7-4	-1.0025	0.3939	0.0000	0.3124
20	8-7	0.0000	1.2921	7-8	0.0000	-1.0446	0.0000	0.2475
						Total losses	3.6277	14.2373

Table 5. Shows the bus voltages without STATCOM under maximum loading condition, it is observed that bus 14 is identified weakest bus among the all other buses and having the voltage magnitude of 0.6815 p.u. Table 7. Shows the line flows and losses in the system without STATCOM under maximum loading condition, it is absorbed that the total real power loss is 5.9058 p.u and reactive power loss is 23.3089 p.u

Table 6. Shows the bus voltages with STATCOM under maximum loading condition, from the result, it is clear that the bus voltage magnitude is improved by inserting STATCOM at bus 14. After inserting STATCOM voltage magnitude at bus 14 is becomes 0.8150 p.u. Table 8. Shows the line flows and losses in the system with STATCOM under maximum loading condition, it is absorbed from the result that the total real power is 3.6277 p.u and reactive loss are 14.2373 p.u

By comparion of table.5 and table.7 Bus voltage magnitude is improved by inserting STATCOM at bus 14 and real power loss is reduced from 5.9058 p.u to 3.6277 p.u and reactive power loss is reduced from 23.3089 p.u to 14.2373 p.u. From the above table, it is observed that STATCOM will improve the voltage stability not only in normal loading condition and also in maximum loading condition of stressed power system.

6. Conclusions

The voltage stability analysis is made for the IEEE 14 bus test system. The NR method is used to analysis the system under normal loading condition and continuation power flow method is used under maximum loading condition. From the result, it is observed that bus voltage magnitude has been improved by providing the reactive power support at bus 14. Hence, we include the STATCOM at bus 14 and the result shows that STATCOM increases the static voltage stability margin and also improve the power transfer capability of the system. However these controllers are expensive when compared to the shunt capacitor.

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Biographies

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