Minimization of Power Loss in Distribution System using SVC and STATCOM

Kamlesh Chandra Sharma[1], Dr. S.K. Sinha[2], Sarva Ruvinigya Somanshu[3]

[1](P.G Scholar) EE Department KNIT Sultanpur, UP (INDIA)-228118
[2](Professor) EE Department KNIT Sultanpur, UP (INDIA)-228118
[3](Assistant Professor) EE Department PIT Jaunpur, UP (INDIA)-222001

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Abstract - *With the advancement of electrical technology, the electrical energy demand has also increased. The demand of electrical energy is also a development parameter of a nation. There is a big issue of a reactive power reserve management. For the shunt compensation of reactive power, we have used SVC and STATCOM. In this paper there is a comparative analysis of triple SVC response with two SVC and a single STATCOM for IEEE 9 and IEEE 14 bus system using Newton Rapshon method in MATLAB environment.*

Key Words: SVC, STATCOM, MATPOWER, MATLAB

1.1 INTRODUCTION

The need for more efficient electricity systems management has given rise to innovative technologies in power generation and transmission. The combined cycle power station is a good example of a new development in power generation and flexible ac transmission systems. Worldwide transmission systems are undergoing continuous changes and restructuring. They are becoming more heavily loaded and are being operated in ways not originally envisioned. [1] Transmission systems must be flexible to react to more diverse generation and load patterns. In addition, the economical utilization of transmission system assets is of vital importance to enable utilities in industrialized countries to remain competitive and to survive in developing countries, the optimized use of transmission systems investments is also important to support industry, create employment and utilize efficiently scarce economic resources. Flexible AC Transmission Systems (FACTS) is a technology that responds to these needs. It significantly alters the way transmission systems are developed and controlled together with improvements in asset utilization, system flexibility and system performance. In my research work I have done comparative analysis between three SVC system with two SVC and single STATCOM for IEEE 9 and IEEE 14 bus system.

1.2 Static Var Compensator (SVC)

Static VAR Compensator (SVC) is a shunt connected FACTS controller whose main functionality is to regulate the voltage at a given bus by controlling its equivalent reactance. Basically it consists of a fixed capacitor (FC) and a thyristor controlled reactor (TCR). The term, "SVC" has been used for shunt connected compensators, which are based on thyristors without gate turn-off capability. It includes separate equipment for leading and lagging VARs, the thyristor controlled or thyristor switched reactor for absorbing reactive power and thyristor switched capacitor for supplying the reactive power.

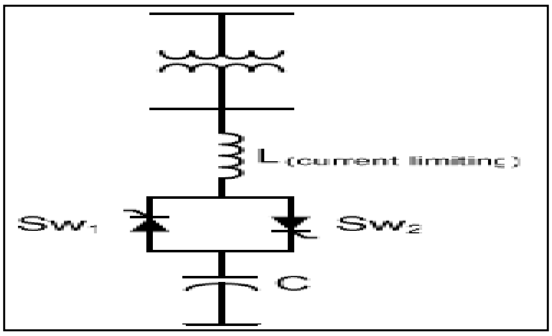

Figure 1: SVC (Static Var compensator)

1.3 SVC FIRING ANGLE MODEL

The equivalent reactance, which is function of a changing firing angle α, is made up of the parallel combination of a thyristor controlled reactor (TCR) equivalent admittance and a fixed capacitive reactance. [3] This model provides information on the SVC firing angle required to achieve a given level of compensation.

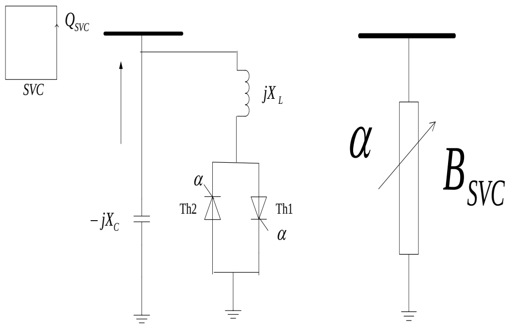

Figure 2: SVC Firing angle model

Fig.3 shows Steady State and Dynamic Characteristics of the SVC. The slope value depends on the desired voltage regulation, the desired sharing of reactive power production between various sources, and other needs of the system. The slope is typically 1 to 5%. At the capacitive limit, the SVC becomes a shunt capacitor. [5] At the inductive limit, the SVC becomes a shunt reactor (the current or reactive power may also be limited).SVC firing angle model is implemented here.

Thus, the model can be developed with respect to a sinusoidal voltage, differential and algebraic equations can be written as

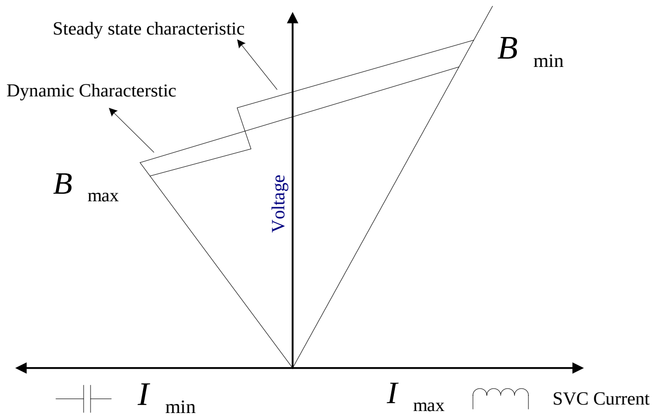

Figure 3: Static and dynamic characteristics

$$I_{svc} = -jB_{svc}V_k \qquad [1]$$

$$X_{TCR} = \frac{\pi X_L}{\sigma - \sin\sigma} \qquad [2]$$

$$\sigma = 2(\pi - \alpha), X_L = \omega L \qquad [3]$$

Where, = conduction angle; α = firing angle
And in terms of firing angle –

$$X_{TCR} = \frac{\pi X_L}{2(\pi - \alpha) + \sin 2\alpha} \qquad [4]$$

At α = 90º, TCR conducts fully and the equivalent reactance becomes
At α= 180º, TCR is blocked and its equivalent reactance becomes infinite. The SVC effective reactance is determined by the parallel combination.

$$X_{SVC} = \frac{\pi X_C X_L}{X_C[2(\pi-\alpha)+\sin 2\alpha] - \pi X_L} \qquad [5]$$

Where
The SVC equivalent reactance is given above

$$B_{SVC} = -1/X_{SVC} \qquad [6]$$

Equation 2 shown in fig 2 profile, as function of firing angle, does not present discontinuities, i.e., varies in a continuous, smooth function in both operative regions. Hence, linearization of the SVC power flow equations, based on B_{SVC} with respect to firing angle, will exhibit a better numerical behaviour than the linearized model based on The initialization of the SVC variables based on the initial values of ac variables and the characteristic of the equivalent susceptance (Fig.2), thus the impedance is initialized at the resonance point $X_{TCR} = X_C$ i.e. $Q_{SVC} = 0$ corresponding to the firing angle for chosen parameter of L and C i.e. $X_L = 0.1134$

1.3 Static Synchronous Compensator (STATCOM)

The STATCOM or SSC (Static Synchronous Compensator) is a shunt-connected reactive-power compensation device that is capable of generating and/ or absorbing reactive power and in which the output can be varied to control the specific parameters of an electric power system. [10] It is in general a solid-state switching converter capable of generating or absorbing independently controllable real and reactive power at its output terminals when it is fed from an energy source or energy-storage device at its input terminals. Specifically, the STATCOM considered is a voltage-source converter that, from a given input of dc voltage, produces a set of 3-phase ac-output voltages, each in phase with and coupled to the corresponding ac system voltage through a relatively small reactance (which is provided by either an interface reactor or the leakage inductance of a coupling transformer).

The dc voltage is provided by an energy-storage capacitor and a STATCOM can improve power-system performance in such areas as the following-

- The dynamic voltage control in transmission and distribution systems.
- The power-oscillation damping in power-transmission systems.
- The transient stability.
- The voltage flicker control.
- The control of not only reactive power but also (if needed) active power in the connected line, requiring a dc energy source.

1.4 Operating Principle of STATCOM

The STATCOM is a controlled reactive-power source. It provides the desired reactive-power generation and absorption entirely by means of electronic processing of the voltage and current waveforms in a voltage-source converter (VSC).

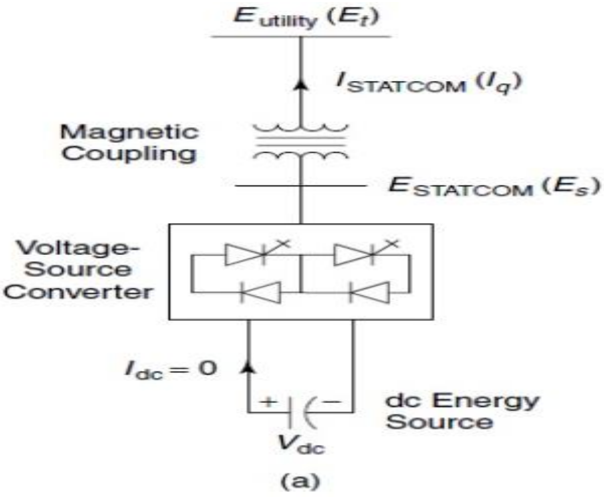

Figure 4: Static synchronous Compensator

understand the compensation principle of STATCOM, two sources V_1 with a phase angle of δ and V_2 with a phase angle of 0° connected together by means of an inductive link of impedance (R +j X) ohms as shown in Fig. 5 are considered. In the STATCOM principle, the source V_1 is the power system voltage at the bus where the STATCOM is connected, V_2 is the AC voltage generated by the STATCOM inverter, X is the reactance in the line, R is the total loss resistance in the link comprising of the winding losses in the link inductor, interface magnetic, the inverter switches and snubber. Assuming is small and R << X, if V_2 represents the STATCOM condition and if the active power flowing into the source V_2 is constrained to be zero, the power delivered by the source V_1 and the reactive power delivered to the link by the source V_2 will be given by the following equations.

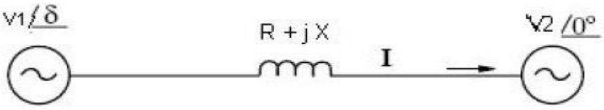

Figure 5: Single line diagram of STATCOM

Active power delivered by V_1 is-

$$P = \left(\frac{V_1^2}{R}\right)\delta^2 \qquad [7]$$

Reactive power delivered by V_2 is-

$$Q = \left(\frac{V_1 V_2}{R}\right)\delta \qquad [8]$$

power drawn from the source V_1 is independent of sign of phase angle (V_1 supply losses only in R and not at V_2) whereas the reactive power delivered by V_2 is directly proportional to the phase angle. [7] The phase angle of V_1 with respect to V_2 is Where, the powers P, Q and voltages V_1, V_2 have phase values. These relations can be used up to about 20° for Active power drawn from the source V_1 is independent of sign of phase angle (V_1 supply losses only in R and not at V_2) whereas the reactive power delivered by V_2 is directly proportional to the phase angle. The phase angle of V_1 with respect to V_2 is

$$\delta = \left(\frac{R}{X}\right)\left(\frac{(V_2 - V_1)}{V_1}\right) \qquad [9]$$

Thus Q is proportional to or equivalently to (V_2-V_1). In the STATCOM, the required AC voltage source V_2 is generated by inverting the DC capacitor voltage. By making the output voltages of the converter lag the AC system voltages by a small angle, the converter absorbs a small amount of active power from the AC system to balance the losses in the converter. But if the active power which goes into the inverter from the source is kept zero, the initially charged capacitor will soon discharge down to zero due to supply of active power losses in the inverter. [11] The DC side voltage will remain constant if the power drawn from source is just enough to supply all the losses which take place everywhere due to the flow of demanded reactive current. The DC side capacitor voltage is

$$V_{dc} = \left(\frac{V_1}{R}\right)\left(1 - \frac{X}{R}\right)\delta \qquad [10]$$

Where, V_1 is the RMS phase voltage of AC mains, k is a constant, which also absorbs the modulation index of PWM process in the inverter. [13] Through appropriate switching sequence, VSC transforms DC voltage at its DC terminals into an AC voltage of controllable frequency, magnitude and phase angle at its terminals. The output voltage could be fixed or variable, at a fixed or variable frequency. For FACTS application purposes, it is always assumed that the output voltage waveform has a fixed frequency equal to the fundamental frequency of a power system to which the converter is connected, as high voltage and power harmonics could create many problems.

2. OBJECTIVE

The main objective of this paper is that to use two SVC and a single STATCOM for three separate distribution line to compensate the reactive power so as to minimize the power loss in IEEE 9 and IEEE 14 bus system

3. Description of the System

In this research paper I have taken two system data (IEEE 9 bus and IEEE 14 bus system) with the help of MATPOWE we make load flow analysis by using newton Rapshon method in MATLAB environment and show the comparative analysis among without compensation, using three SVC and two SVC with a single STATCOM. The following tables shows the system parameters.

3.1 IEEE 9 BUS SYSTEM PARAMETER

Table 1: System details

Buses	Generators	Committed Gens
9	3	4

Loads	Fixed	Dispatchable
4	0	0

Shunts	Branches	Transformers
9	0	0

Inter-ties	Parameter	Total Gen Capacity
0	P (in MW)	820
-	Q (in MVAR)	-900 to 900

On-line capacity	Generation (actual)	load
820	324.8	315
-900 to 900	-900 to 900	-759.6

Parameter	Dispatchable	Shunt (inj)
P (in MW)	-0.0 of -0.0	-0.0
Q (in MVAR)	0	0

Losses I^2Z	Branch charging	Quantity
9.8	-	Min value
9.8	172.4	Max value

Voltage magnitude	Voltage angle	P Losses I^2R	P Losses I^2X
1.000 p.u. @ bus 2	-4.65 deg @ bus 9	-	-
1.208 p.u. @ bus 9	-7.45 deg @ bus 2	3.22 MW @ bus 8-9	38.18 MVAR @ line 8-2

TABLE 1.1 BUS DATA (IEEE-9)

Bus No.	**Voltage**	
	Mag(pu)	Ang(deg)
1	1.000	0.000*
2	1.000	7.449
3	1.000	3.880
4	1.088	-2.331
5	1.074	-3.725
6	1.085	1.248
7	1.196	-0.571
8	1.121	2.234
9	1.208	-4.650
Total	**9.772**	**3.534**

	Generation	
Bus No.	P (MW)	Q (MVAr)
1	76.80	-150.85
2	163.00	-185.78
3	85.00	422.97
4	-	-
5	-	-
6	-	-
7	-	-
8	-	-
9	-	-
Total	**324.80**	**-759.60**

Bus No	**Load**	
	P (MW)	Q (MVAr)
1	-	-
2	-	-
3	0.00	-280.00
4	-	-
5	90.00	30.00
6	-	-
7	100.00	-245.00
8	-	-
9	125.00	-230.00
Total	**315.00**	**-725.00**

Table 1.2 BRANCH DATA

Branch	**From bus**	**To bus**
1	1	4
2	4	5
3	5	6
4	3	6
5	6	7
6	7	8
7	8	2
8	8	9
9	9	4
Total	**51**	**51**

Bus No.	From bus injection	
	P (MW)	Q (MVAr)
1	76.80	-150.85
2	32.80	0.85
3	-57.37	-11.60
4	85.00	-142.97
5	26.49	-134.02
6	-75.07	124.93
7	-163.00	223.95
8	86.50	-91.11
9	-41.73	164.22
Total	**-29.58**	**-16.60**

Bus No	To Bus Injection	
	P (MW)	Q (MVAr)
1	-76.80	167.35
2	-32.63	-18.40
3	58.51	-25.16
4	-85.00	159.18
5	-24.93	120.07
6	76.50	-132.85
7	163.0	-185.78
8	-83.27	65.78
9	43.99	-168.20
Total	**39.37**	**9.796**

Bus No	Loss (I2 Z)	
	P (MW)	Q (MVAr)
1	0.000	16.50
2	0.170	0.92
3	1.140	4.97
4	0.000	16.21
5	1.569	13.29
6	1.428	12.10
7	0.000	38.18
8	3.223	16.21
9	2.268	19.28
Total	**137.6**	**9.7964**

3.2 IEEE 14 BUS SYSEM PARAMETER

Table 2: SYSTEM DETAILS

Buses	Generators	Committed Gens
14	5	5

Load	Fixed	Dispatchable
11	11	0

Shunt	Branches	Transformers
1	20	3

Inter – ties	Parameter	Total Gen Capacity
0	P	772.4

	(in MW)	
-	Q (in MVAR)	-52.0 to 148.0

On-line capacity	Generation (actual)	load
772.4	484.4	259.0
-52.0 to 148.0	-233.8	-811.5

Parameter	Dispatchable	Shunt (inj)
P (in MW)	-0.0 of -0.0	-0.0
Q (in MVAR)	-0.0	33.6

Losses I^2Z	Branch charging	Quantity
225.36	-	Min value
635.64	24.4	Max value

Voltage magnitude	Voltage angle	P Losses I^2R	P Losses I^2X
1.010 p.u. @ bus 3	-52.27 deg @ bus 14	-	-
1.929 p.u. @ bus 14	0.00 deg @ bus 1	82.54 MW @ bus 9-14	175.56 MVAR @ line 9-14

Table 2.1: BUS DATA (IEEE-14)

Branch No.	Voltage	
	Mag(pu)	Ang(deg)
1	1.060	0.000*
2	1.045	-9.550
3	1.010	-20.278
4	1.023	-20.742
5	1.011	-17.665
6	1.070	-30.094
7	1.185	-31.124
8	1.090	-31.124
9	1.330	-35.401
10	1.277	-34.947
11	1.171	-33.014
12	1.156	-33.997
13	1.232	-38.582
14	1.929	-52.272
Total:	16.589	-388.79

Bus No	Generation	
	P (MW)	Q (MVAr)
1	444.36	-39.79
2	40.00	85.01
3	0.00	22.10
4	-	-
5	-	-
6	0.00	-242.55
7	-	-

8	0.00	-58.60
9	-	-
10	-	-
11	-	-
12	-	-
13	-	-
14	-	-
Total:	**484.36**	**-233.82**

Bus No	Load	
	P (MW)	Q (MVAr)
1	-	-
2	21.70	12.70
3	94.20	19.00
4	47.80	-3.90
5	7.60	1.60
6	11.20	7.50
7	-	-
8	-	-
9	29.50	16.60
10	9.00	5.80
11	3.50	1.80
12	6.10	1.60
13	13.50	5.80
14	14.90	-880.00
Total:	**259.00**	**-811.50**

Table 2.3: BRANCH DATA

Branch No	From bus	To bus
1	1	2
2	1	5
3	2	3
4	2	4
5	2	5
6	3	4
7	4	5
8	4	7
9	4	9
10	5	6
11	6	11
12	6	12
13	6	13
14	7	8
15	7	9
16	9	10
17	9	14
18	10	11
19	12	13
20	13	14
Total:	**113**	**165**

Branch No	From bus injection	
	P (MW)	Q (MVAr)
1	296.13	-47.14
2	148.23	7.35
3	100.19	1.62
4	113.46	-14.60
5	285.3	-3.21
6	1.67	-8.88
7	-110.3	67.74
8	106.78	-59.73
9	63.86	-43.79
10	99.10	17.06
11	5.26	-56.20
12	13.11	-41.24
13	69.53	-157.21
14	-0.00	63.69
15	106.78	-152.04
16	13.42	77.98
17	127.72	-313.81
18	3.29	69.19
19	5.00	-47.02
20	40.26	-247.00
Total:	**1488.79**	**-887.24**

Bus No	To bus injection	
	P (MW)	Q (MVAr)
1	-280.67	88.50
2	-137.61	31.19
3	-95.87	11.98
4	-106.52	32.01
5	-81.52	11.15
6	-1.62	7.67
7	112.44	-61.00
8	-106.78	88.35
9	-63.86	73.72
10	-99.10	4.60
11	-2.62	61.74
12	-11.10	45.42
13	-52.46	190.84
14	0.00	-58.60
15	-106.78	179.10
16	-12.29	-74.99
17	-45.18	489.37
18	-0.88	-63.54
19	-1.30	50.37
20	30.28	390.63
Total:	**-1063.44**	**225.36**

Branch No	Loss (I2 Z)	
	P (MW)	Q (MVAr)
1	15.462	47.21
2	10.615	43.82
3	4.326	18.23
4	6.937	21.05
5	3.797	11.59
6	0.046	0.12
7	2.138	6.74
8	0.000	28.62

9	0.000	29.93
10	0.000	21.67
11	2.643	5.54
12	2.010	4.18
13	17.074	33.62
14	-58.60	5.09
15	0.000	27.06
16	1.127	2.99
17	82.536	175.56
18	2.415	5.65
19	3.695	3.34
20	70.542	143.63
Total:	**635.64**	**225.36**

4. RESULTS

There is a comparative results tabulated below for IEEE 9 bus System and IEEE 14 bus system. The comparison is in between without controller, with three SVC and two SVC with a Single STATCOM

4.1. IEEE 9 Bus System Results

Table 3: shows different power ratings of SVC and STATCOM with respective power losses.

Power Ratings of SVCs and STATCOM (in MVAR)	Power loss with 3 SVC (in MVA)	Power loss with 2 SVC+1 STATCOM (in MVA)
5	4.8299	4.8299
30	4.5791	4.5352
55	4.4749	4.3871
80	4.4517	4.32
105	4.3263	4.1507
130	4.2043	3.9848
155	4.0906	3.8271
180	3.9841	3.6768
205	3.8843	3.533
230	3.7905	3.3953
255	3.7021	3.263
280	3.6186	3.1356

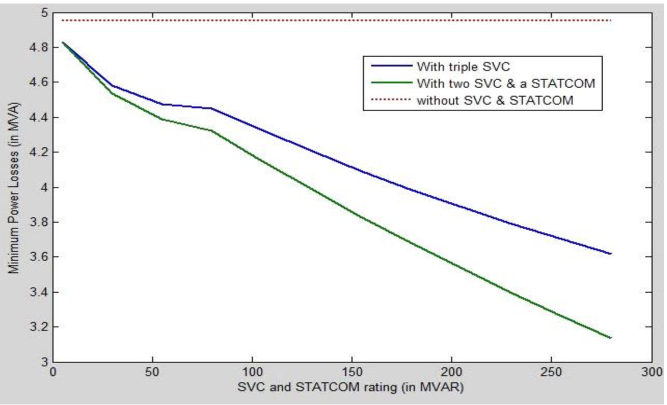

Figure 6: Comparative plot for Power loss in IEEE 9 bus system.

Red line shows power losses of IEEE 9 bus system without any controller, Blue line indicates the different plot of 3 SVC and green line shows the plot of 2 SVC + 1 STATCOM The result shows that without any controller power loss is 4.95 MVA, with 3 SVC power losses are varying from 4.8299 MVA to 3.6186 MVA, and with 2 SVC and 1 STATCOM power losses are varying from 4.829 MVA to 3.1356 MVA.

4.2 IEEE 14 Bus System Results

This case incudes result findings of IEEE 14 bus system (shown in Fig. 7) in MATLAB environment and MATPOWER Version 5.1, AC Power Flow (Newton). Parameters used in these system data given in table 2, bus data given in table 2.1, branch data given in table 2.3 and result data given in table 4

Table 4: Shows different power ratings of SVC and STATCOM with respective power losses.

Power Ratings of SVCs and STATCOM (in MVAR)	Power loss with 3 SVC (in MVA)	Power loss with 2 SVC+1 STATCOM (in MVA)
5	13.2998	13.2998
15	13.2896	13.2434
25	13.3141	13.2217
35	13.3178	13.1792
45	13.3409	13.1562
55	13.3831	13.1522
65	13.3933	13.1162
75	13.3933	13.0700
85	13.3933	13.0238
95	13.3933	12.9776
105	13.3933	12.9314
115	13.3933	12.8853
125	13.3933	12.8391
135	13.3933	12.7929

145	13.3933	12.7467
155	13.3933	12.7005
165	13.3933	12.6543
175	13.3933	12.6081
185	13.3933	12.5620
195	13.3933	12.5158
205	13.3933	12.4696
215	13.3933	12.4234
225	13.3933	12.3772
235	13.3933	12.3310
245	13.3933	12.2849
255	13.3933	12.2387
265	13.3933	12.1925
275	13.3933	12.1463
285	13.3933	12.1001
295	13.3933	12.0539

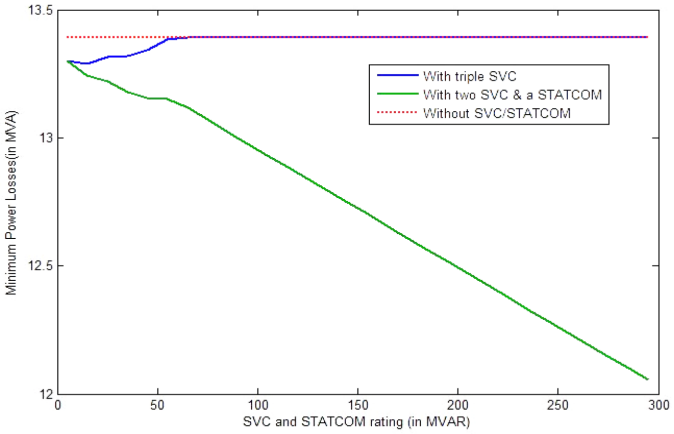

Figure 7: Comparative plot for Power loss in IEEE 14 bus system

Red line shows power losses of IEEE 14 bus system without any controller, Blue line indicates the different values of power loss with 3 SVC and green line shows the value of power loss with 2 SVC + 1 STATCOM.

4. CONCLUSION

The proposed dissertation work concludes that –

1. For IEEE-9 bus system: With 3 SVC power losses are varying from 4.829 to 3.6186, and with 2 SVC and 1 STATCOM power losses are varying from 4.829 to 3.1356.
2. For IEEE-14 bus system: With 3 SVC power losses are varying from 13.298 to 13.933, and with 2 SVC and 1 STATCOM power losses are varying from 13.298 to 12.0539.

From the above two conclusions it is observed that power saving is more in case of IEEE 14 bus system as compare to power loss in case of IEEE 9 BUS system. So this technique is suitable for large power system.

In general, this dissertation work focused on the problem of power loss compensation from two aspects, directly and indirectly. The effect which has been observed directly in dissertation work, already discussed in previous paragraph. Indirectly the proposed work also improves the other aspects like –

- •Increase the value of the system power factor.
- •Balance the real power drawn from the ac supply.
- •Eliminate current harmonic components produced by large and fluctuating nonlinear industrial loads.
- •Voltage support is generally required to reduce voltage fluctuation at a given terminal of a transmission line.
- •Power loss minimization using SVC and STATCOM reactive compensation in transmission systems.
- •Improves the stability of the ac system by increasing the maximum active power that can be transmitted.

This dissertation work investigates the application of a STATCOM and SVC to help with the uninterrupted operation of IEEE 9 bus and 14 bus systems equipped with a STATCOM and 2 SVC's during power flow operations. The SVC and STATCOM power rating control schemes are suitably applying and coordinated.

The proposed dissertation work can be performed with other AI techniques to obtain better performance and minimization of power losses. Also it can be used for FACTs optimal placements to enhance IEEE bus systems quality.

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