Analyzing the Power System in the Presence of FACTS Controllers: Effect of Control Parameters

P. Paul Clee, S.V.L. Narasimham

Abstract— ***Now a day technological development in power electronics based controllers formerly known as Flexible AC Transmission Controllers (FACTS), the power system can operate with high security. These controllers help to enhance the transmission line loadings in terms of its thermal ratings. The line loadings and bus voltage profiles can be controlled using these FACTS controllers. To analyze the effect of the FACTS devices, these controllers should be incorporated in a given system and the load flow analysis is performed using Newton Raphson (NR) method. In this paper, very popularly used FACTS controllers known for Static VAr Compensator (SVC) and Thyristor Controlled Series Compensator (TCSC) are considered. The effect of these devices on system bus voltages, line power flows and system power losses is analyzed on standard test system such as HALE network and IEE-30 bus test systems are considered.***

Index Terms—Power flow analysis, SVC, TCSC, NR-load flow, Optimal location.

I. INTRODUCTION

Now a day the power system becomes more complex to operate and system becomes less secure for riding through the major outages. The power system must be capable to withstand for the loss of any power system components without disturbing the normal operation. The single line outage is commonly used for security analysis of the power system. Based on this criterion, critical contingency lines have been identified and ranking is given. The analysis of optimal power flow problem with outage comes under the security constrained optimal power flow problem. The outage in the power system leads to over loading of lines voltage violation at the buses. There is need to avoid over loading of lines and maintain required voltages at the buses for secure operation. The facts devices will help to maintain the system security under contingencies by reducing the power flows of heavily loaded lines and maintain the bus voltage magnitude at desired levels.

Recently there has been growing interest in allocation of FACTS devices for relieving transmission congestion as well as improving voltage stability. References [1] and [2] have proposed optimal allocation methods for thyristor controlled series capacitor (TCSC) to eliminate the line over loads against contingencies, where sensitivity index is introduced for ranking the optimal placement. Optimal allocation method for static VAr compensator (SVC) has been proposed in [3]. Priority list method for TCSC allocation for congestion management has been proposed in [4]. In [5] and [6], met heuristic techniques such as particle swarm optimization (PSO), genetic algorithm, and simulated annealing have been used to find optimal locations of FACTS devices in order to minimize installation cost and to improve system loadability.

Generally, FACTS devices are able to relieve congestions and decrease power losses as well as to reduce load shedding [7-9] and generation re-scheduling [10], which may significantly contribute to decreasing annual cost of power system operation. Load flow studies [11]-[12] are used to ensure that electrical power transfer from generators to consumers through the grid system is stable, reliable and economic. Conventional techniques for solving the load flow problem are iterative, using the Newton-Raphson or the Gauss-Seidel methods [13]-[14]. Load flow analysis forms an essential prerequisite for power system studies. Considerable research has already been carried out in the development of computer programs for load flow analysis of large power systems. However, these general purpose programs may encounter convergence difficulties when a radial distribution system with a large number of buses is to be solved and, hence, development of a special program for radial distribution studies becomes necessary [15]. There are many solution techniques for load flow analysis. The solution procedures and formulations can be precise or approximate, with values adjusted or unadjusted, intended for either on-line or off- line application, and designed for either single-case or multiple- case applications. Since an engineer is always concerned with the cost of products and services, the efficient optimum economic operation and planning of electric power generation system have always occupied an important position in the electric power industry. With large interconnection of the electric networks, the energy crisis in the world and continuous rise in prices, it is very essential to reduce the running charges of the electric energy [16]- [17]. A saving in the operation of the system of a small percent represents a significant reduction in operating cost as well as in the quantities of fuel consumed. The classic problem is the economic load dispatch of generating systems to achieve minimum operating cost.

This problem area has taken a subtle twist as the public has become increasingly concerned with environmental matters, so that economic dispatch now includes the dispatch of systems to minimize pollutants and conserve various forms of fuel, as well as achieve minimum cost [18]. In addition there is a need to expand the limited economic optimization problem to incorporate constraints on system operation to ensure the security of the system,

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thereby preventing the collapse of the system due to unforeseen conditions [19]. However closely associated with this economic dispatch problem is the problem of the proper commitment of any array of units out of a total array of units to serve the expected load demands in an „optimal" manner [20]. For the purpose of optimum economic operation of this large scale system, modern system theory and optimization techniques are being applied with the expectation of considerable cost savings

Through the load flow studies we can obtain the voltage magnitudes and angles at each bus in the steady state. This is rather important as the magnitudes of the bus voltages are required to be held within a specified limit. Once the bus voltage magnitudes and their angles are computed using the load flow, the real and reactive power flow through each line can be computed [11, 12]. Also based on the difference between power flow in the sending and receiving ends, the losses in a particular line can also be computed. Furthermore, from the line flow we can also determine the over and under load conditions. The steady state power and reactive power supplied by a bus in a power network are expressed in terms of nonlinear algebraic equations. We therefore would require iterative methods for solving these equations. In this paper we shall discuss the load flow method of Newton Raphson on IEEE 5 and 30 bus systems with SVC and TCSC Controllers.

In this paper, SVC and TCSC is analyzed by varying the controller parameters. The variation of system bus voltage magnitude, line apparent power flow and system active power loss variations are analyzed for standard HALE and IEEE-30 bus test systems. The numerical and graphical results confirm that, there is an effect of device control parameters on the system parameters.

II. MODELING OF FACTS CONTROLLERS

A. Thyristor controlled series capacitor

Series compensation is an important method of improving the performance of EHV transmission lines. It consists of capacitors connected in series with the line at suitable locations and thus opposes directly the effect of series inductive reactance of the line. It increases the power handling capacity and reduces the voltage regulation as explained below. The basic model of TCSC is shown in Fig.1.

The power transfer capability of a transmission line is given as

$$P = \frac{V_s V_r}{X_L} \sin\delta \qquad (1)$$

With the insertion of capacitor having capacitive reactance 'X_C' in the line, the net reactance of the line becomes (X_L-X_C) and the power transfer capability of the line is given as

$$P^{new} = \frac{V_s V_r}{(X_L - X_C)} \sin\delta \qquad (2)$$

From the above equations 1 and 2 it is obvious that for the same magnitudes of V_s, V_r and δ, P^{new} is much higher than P and the increase in power transfer capability is given as

$$\frac{P^{new}}{P} = \frac{1}{1-k} \qquad (3)$$

Where, 'k' is the degree of compensation and equals to $\frac{X_C}{X_L}$.

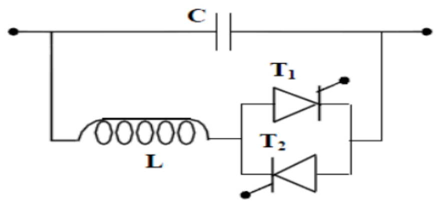

Fig.1. Basic model of TCSC

Fig.2 shows a π model of transmission line with TCSC connected between bus-k and bus-m. Under the steady state condition, the TCSC can be represented as a static reactance -jX_C. In the power flow equations the controllable reactance X_C is directly used as the control variable.

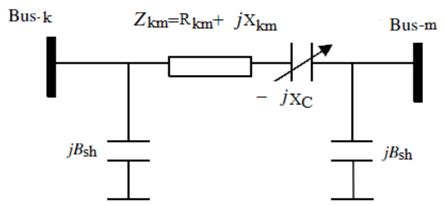

Fig.2. Transmission line with TCSC

Therefore new line admittance between buses k and m can be derived as follows

$$Y'_{km} = \frac{1}{Z'_{km}} = \frac{1}{R_{km} + j(X_{km} - X_C)} \qquad (4)$$

$$Y'_{km} = G'_{km} + jB'_{km} = \frac{R_{km} - j(X_{km} - X_C)}{R_{km}^2 + (X_{km} - X_C)^2} \qquad (5)$$

Where,

$$G'_{km} = \frac{R_{km}}{R_{km}^2 + (X_{km} - X_C)^2} \quad B'_{km} = -\frac{(X_{km} - X_C)}{R_{km}^2 + (X_{km} - X_C)^2}$$

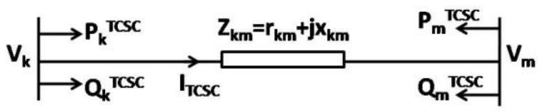

Fig.3. Power injection model of TCSC

Due to TCSC, the change in line flow can be represented as a line without TCSC plus with power injected at the sending and receiving ends of the line with device as shown in Fig.3. The active and reactive power injections at bus-k and bus-m can be written as

$$P_k^{TCSC} = V_k^2 \Delta G_{km} - V_k V_m [\Delta G_{km} Cos(\delta_{km}) + \Delta B_{km} Sin(\delta_{km})] \qquad (6)$$

$$P_m^{TCSC} = V_m^2 \Delta G_{km} - V_k V_m [\Delta G_{km} Cos(\delta_{km}) - \Delta B_{km} Sin(\delta_{km})] \qquad (7)$$

$$Q_k^{TCSC} = -V_k^2 \Delta B_{km} - V_k V_m [\Delta G_{km} Sin(\delta_{km}) - \Delta B_{km} Cos(\delta_{km})] \qquad (8)$$

$$Q_m^{TCSC} = -V_m^2 \Delta B_{km} + V_k V_m [\Delta G_{km} Sin(\delta_{km}) + \Delta B_{km} Cos(\delta_{km})] \qquad (9)$$

Where

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$$\Delta G_{km} = \frac{X_C R_{km}(X_C - 2X_{km})}{(R_{km}^2 + X_{km}^2)(R_{km}^2 + (X_{km} - X_C)^2)}$$

$$\Delta B_{km} = \frac{-X_C(R_{km}^2 - X_{km}^2 + X_C X_{km})}{(R_{km}^2 + X_{km}^2)(R_{km}^2 + (X_{km} - X_C)^2)}$$

B. Static VAr compensator:

It is a bank of three-phase static capacitors and/or inductors. Under heavy loading conditions, when positive VArs are needed, capacitor banks are needed, when negative VArs are needed, inductor banks are used. In this thesis SVC is modeled as an ideal reactive power injection at bus j, the amount of reactive power injected into the bus j is given as follows.

In practice the SVC can be seen as an adjustable reactance with either firing-angle limits or reactance limits. The equivalent circuit shown in Fig.4 is used to derive the SVC nonlinear power equations and the linearized equations required by Newton‘s method. With reference to Fig.4, the current drawn by the SVC is

$$I_{SVC} = jB_{SVC}V_k \tag{10}$$

And the reactive power drawn by the SVC, which is also the reactive power injected at bus-i, is

$$Q_{SVC} = Q_i = -V_i^2 B_{SVC} \tag{11}$$

It is a bank of three-phase static capacitors and/or inductors. Under heavy loading conditions, when positive VAr is needed, capacitor banks are needed, when negative VAr is needed, inductor banks are used.

Fig.4. Mathematical power injection modeling of SVC

III. COMPUTATIONAL PROCEDURE

The Load flow incorporation procedure and overall computation procedure with FACTS is described in this section.

A. TCSC computational procedure

Then new power flow equations can be expressed by the following relationship

$$\begin{bmatrix}\Delta P\\ \Delta Q\end{bmatrix} = \begin{bmatrix}H_{new} & M_{new}\\ N_{new} & L_{new}\end{bmatrix} \cdot \begin{bmatrix}\Delta\delta\\ \frac{\Delta V}{V}\end{bmatrix} \tag{12}$$

Where new mismatch vectors are

$$\Delta P_i = P_k^{spec} + P_k^{TCSC} - P_k^{calc}$$

$$\Delta Q_i = Q_k^{spec} + Q_k^{TCSC} - Q_k^{calc}$$

P_k^{spec} and Q_k^{spec} are the classical specified real and reactive powers, P_k^{TCSC} and Q_k^{TCSC} are the power injection associated to TCSC devices, P_k^{calc} and Q_k^{calc} are computed using the power flow equations. Now modified Jacobian matrix due to power injections of TCSC

$$H_{new} = H + \frac{\partial P^{TCSC}}{\partial\delta} \; ; \; M_{new} = M + \frac{\partial P^{TCSC}}{\partial V}V$$

$$N_{new} = N + \frac{\partial Q^{TCSC}}{\partial\delta} \; ; \; L_{new} = L + \frac{\partial Q^{TCSC}}{\partial V}V$$

H, M, N and L are the classic sub-Jacobian.

B. SVC computational procedure

The linearized equation is given by Equation (13), where the equivalent susceptance B_{SVC} is taken to be the state variable

$$\begin{bmatrix}\Delta P_k\\ \Delta Q_k\end{bmatrix}^i = \begin{bmatrix}0 & 0\\ 0 & Q_k\end{bmatrix}^i \begin{bmatrix}\Delta\theta_k\\ \Delta B_{SVC}/B_{SVC}\end{bmatrix}^i \tag{13}$$

At the end of iteration (i), the variable shunt susceptance B_{SVC} is updated according to

$$B_{SVC}^{i+1} = B_{SVC}^i + \left(\Delta B_{SVC}/B_{SVC}\right)^i B_{SVC}^i$$

The changing susceptance represents the total SVC susceptance necessary to maintain the nodal voltage magnitude at the specified value. Once the level of compensation has been computed then the thyristor firing angle can be calculated.

IV. OPTIMAL LOCATION

In this section, a methodology to select an optimal location to install FACTS controllers is described in the following steps.

A. Tcsc Location

Step.1: Read bus and line data.
Step.2: Perform NR load flow.
Step.3: Obtain voltage magnitude at system buses.
Step.4: Calculate line active, reactive and apparent power flows.
Step.5: Calculate line margins using (Margin=Line limit-Line flow)
Step.6: Identify a line which has highest line margin.
Step.7: Place TCSC in that line and perform NR load flow with TCSC.
Step.8: Perform load flow analysis by varying the device control parameters such as X_{TCSC}.

B. SVC Location

Step.1: Read bus and line data.
Step.2: Perform NR load flow.
Step.3: Obtain voltage magnitude at system buses.
Step.4: Calculate line active, reactive and apparent power flows.
Step.5: Identify a bus which has least voltage magnitude.
Step.6: Place SVC at this bus and perform NR load flow with SVC.
Step.8: Perform load flow analysis by varying the device control parameters such as B_{SVC}.

V. RESULTS AND ANALYSIS

In this section, the proposed methodology is tested on standard Hale and IEEE-30 bus test systems.

A. Example-1

Here, Hale network with 5 buses and 7 transmission lines is considered to analyze the proposed methodology.

For this system the power flow result, which includes, bus voltage magnitudes, line flows and system power losses are given in tables, 1,2 and 3.

From Table.1, it is identified that, the bus voltage is least at bus-5. Hence, bus-5 is selected as an optimal bus to install SVC. Similarly, from Table.2, it is identified that, margin is high for 3rd line i.e. between buses 2 and 3. Hence, this line is considered to install TCSC. The further analysis is performed by placing SVC and TCSC in these optimal locations.

Table.1. Voltage magnitudes and angles at system buses of Hale network

Bus No.	Voltage magnitude (p.u.)	Voltage angle (deg)
1	1.0600	0
2	1.0000	-2.0612
3	0.9872	-4.6367
4	0.9841	-4.9570
5	**0.9717**	**-5.7649**

Table.2. Power flow in transmission lines of Hale network

Line No.	Active Power flow (MW)	Reactive Power Flow (MVAr)	Apparent Power flow (MVA)	Line limit (MVA)	Margin (MVA)
1 (1-2)	89.3314	73.9952	115.9973	120	4.0027
2 (1-3)	41.7908	16.8203	45.0488	50	4.9512
3 (2-3)	**24.4727**	**-2.5185**	**24.6019**	**30**	**5.3981**
4 (2-4)	27.7130	-1.7239	27.7666	30	2.2334
5 (2-5)	54.6599	5.5579	54.9417	60	5.0583
6 (3-4)	19.3862	2.8648	19.5967	23	3.4033
7 (4-5)	6.5983	0.5183	6.6186	10	3.3814

Table.3. Power system losses in Hale network

Description	Value
Active power loss (MW)	6.1222
Reactive power loss (MVAr)	10.7773

1) SVC analysis

In this section, the analysis of power system in the presence of SVC is presented. The SVC control parameters i.e. Q_{SVC} is varied from -25 MVAr to +25 MVAr in steps of 10 MVAr.

The obtained bus voltage magnitudes, line apparent power flows and system losses are given in tables, 4, 5 and 6.

Table.4. Voltage magnitudes at system buses with SVC

Bus No.	Voltage magnitudes (p.u.)					
	Q_{SVC}=-0.25 p.u.	Q_{SVC}=-0.15 p.u.	Q_{SVC}=-0.05 p.u.	Q_{SVC}=0.05 p.u.	Q_{SVC}=0.15 p.u.	Q_{SVC}=0.25 p.u.
1	1.06	1.06	1.06	1.06	1.06	1.06
2	1	1	1	1	1	1
3	0.98322	0.984813	0.986429	0.988071	0.989738	0.99143
4	0.978958	0.981003	0.983081	0.985191	0.987334	0.989511
5	0.950598	0.958934	0.967407	0.97602	0.984777	0.99368

Table.5. Apparent power flow in transmission lines with SVC

Line No	Apparent power flow (MVA)					
	Q_{SVC}=-0.25 p.u.	Q_{SVC}=-0.15 p.u.	Q_{SVC}=-0.05 p.u.	Q_{SVC}=0.05 p.u.	Q_{SVC}=0.15 p.u.	Q_{SVC}=0.25 p.u.
1	116.1607	116.0769	116.0175	115.9837	115.9769	115.9985
2	45.79772	45.48791	45.19156	44.91001	44.64469	44.39713
3	24.57656	24.56239	24.58039	24.63201	24.71864	24.84154
4	27.844	27.77694	27.75758	27.78839	27.87169	28.00959
5	59.2817	56.95996	55.40005	54.71378	54.98263	56.24297
6	20.58365	20.11262	19.74101	19.48227	19.34924	19.35336
7	9.71516	8.035868	6.884228	6.610989	7.378159	8.976226

Table.6. System power losses with SVC

Description	Power losses					
	Q_{SVC}=-0.25 p.u.	Q_{SVC}=-0.15 p.u.	Q_{SVC}=-0.05 p.u.	Q_{SVC}=0.05 p.u.	Q_{SVC}=0.15 p.u.	Q_{SVC}=0.25 p.u.
Active power loss (MW)	6.490252	6.302933	6.168617	6.09018	6.070649	6.113213

Reactive power loss (MVAr)	-9.41153	-10.0764	-10.5847	-10.9276	-11.0962	-11.0811

Similarly, the variation of voltage magnitudes, line apparent power flows and system power losses are shown in Figs.5, 6 and 7.

From these figures it is identified that, because of placing SVC at bus 5, the voltage magnitude has major variation at bus 5. As Q_{SVC} is increased from negative value to the positive value i.e. from -0.25 p.u. to 0.25 p.u the voltage magnitude value is increased.

Similarly, from Fig. 6, due to SVC at bus-5, the lines which are connected to 5th bus have considerable variation as the voltage has variations.

From Fig.7, it is identified that, active power losses are minimum when SVC is at 0.15 p.u. and maximum when SVC is at -0.25 p.u.

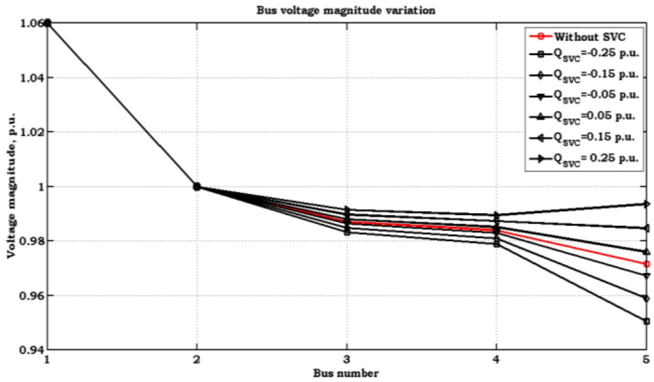

Fig.5. Variation of bus voltage magnitude with SVC for Hale network

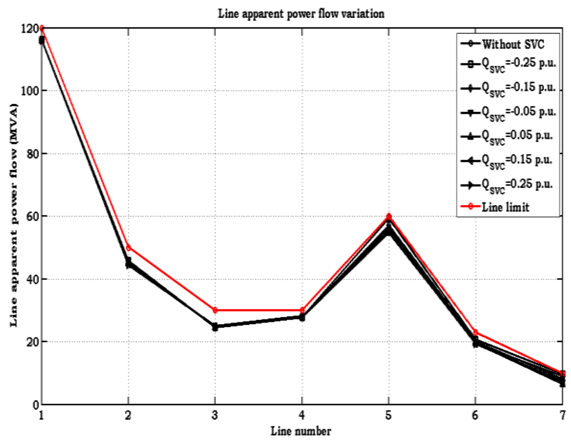

Fig.6. Variation of line apparent power flow with SVC for Hale network

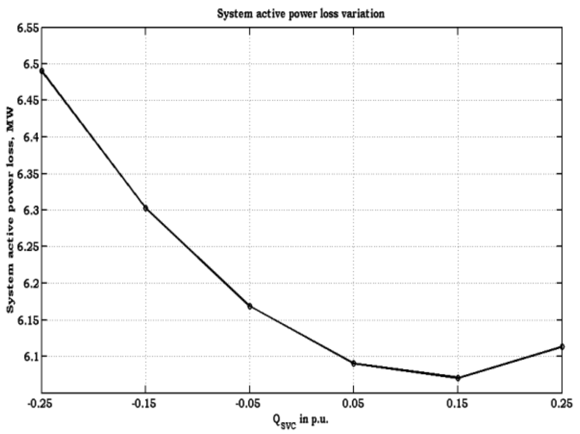

Fig.7. Variation of system active power loss with SVC for Hale network

2) TCSC analysis

In the similar way, the variation of bus voltage magnitudes, line apparent power flows and system power losses in the presence of TCSC are shown in Figs. 231. Here, the TCSC control parameter X_{TCSC} is varied from -0.8Xline to 0.2 Xline. i.e. from -0.144 p.u. to 0.036 p.u. in steps of 0.03 p.u.

Similarly, the variation of voltage magnitudes, line apparent power flows and system power losses are shown in Figs.8, 9 and 10.

From these figures it is identified that, because of placing TCSC in line-3, there is no significant voltage magnitude variation is observed as it is a series device.

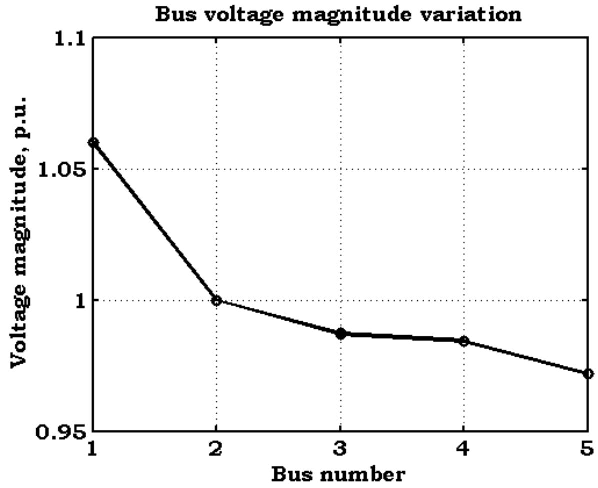

Fig.8. Variation of bus voltage magnitude with TCSC for Hale network

Similarly, from Fig. 9, due to TCSC in line-3, the TCSC connected line and the lines which are connected to buses 2 and 3 have considerable variation. From Fig.10, it is identified that, active power losses are decreased as X_{TCSC} is increased from its minimum value to maximum value.

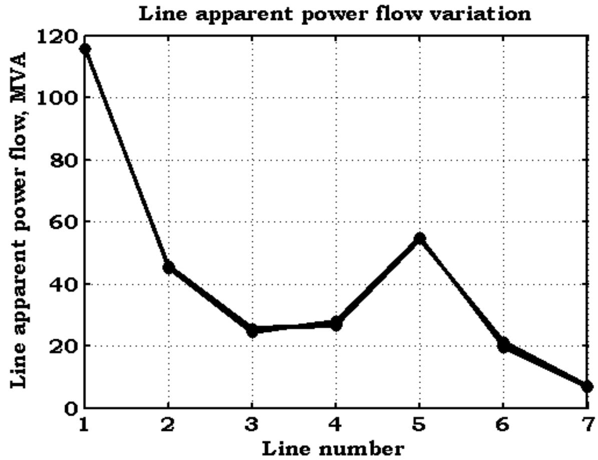

Fig.9. Variation of line apparent power flow with TCSC for Hale network

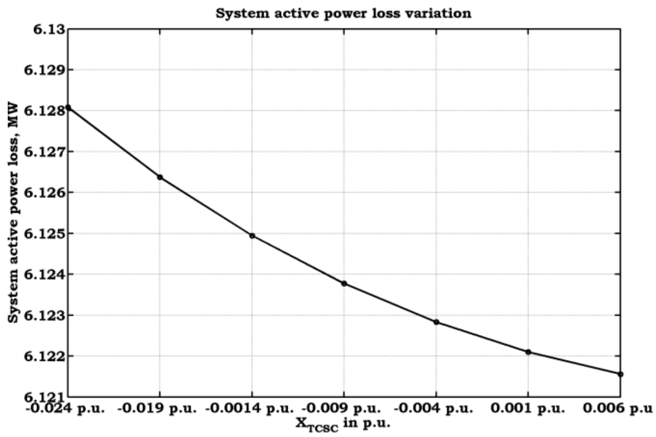

Fig.10. Variation of system active power loss with TCSC for Hale network

B. Example-2

Here, IEEE-30 bus system with 30 buses and 41 transmission lines is considered to analyze the proposed methodology.

For this system the power flow result, which includes, bus voltage magnitudes, line flows and system power losses are given in tables, 7, 8 and 9.

From Table.7, it is identified that, the bus voltage is least at bus-26. Hence, bus-26 is selected as an optimal bus to install SVC. Similarly, from Table.8, it is identified that, margin is high for 9^{th} line i.e. between buses 6 and 7. Hence, this line is considered to install TCSC. The further analysis is performed by placing SVC and TCSC in these optimal locations.

Table.7. Voltage magnitudes and angles at system buses of IEEE-30 bus system

Bus No.	Voltage magnitude (p.u.)	Voltage angle (deg)
1	1.06	0
2	1.03892	-5.47247
3	1.014611	-7.96086
4	1.004995	-9.62302
5	1.01	-14.5243
6	1.001499	-11.3517
7	0.996694	-13.1771
8	1.01	-12.264
9	0.983821	-14.64
10	0.950253	-16.4721
11	1.032185	-14.64
12	0.982653	-16.1574
13	1.015732	-16.1574
14	0.96366	-17.1339
15	0.956249	-17.1105
16	0.961237	-16.5998
17	0.947755	-16.7556
18	0.940849	-17.7149
19	0.935144	-17.847
20	0.938069	-17.5697
21	0.936627	-16.967
22	0.937232	-16.9361
23	0.938915	-17.3269
24	0.924937	-17.2016
25	0.940703	-16.9152
26	**0.921522**	**-17.4076**
27	0.959828	-16.4165
28	0.996513	-12.0133
29	0.938519	-17.8183
30	0.926201	-18.829

Table.8. Power flow in transmission lines of IEEE-30 bus system

Line No.	Active power flow (MW)	Reactive power flow (MVAr)	Apparent power flow (MVA)	Line limit (MVA)	Margin
1	178.625	-13.5387	179.1373	200	20.863
2	83.17889	10.12825	83.79325	130	46.207
3	45.75475	5.859794	46.12846	65	18.872
4	77.9445	-0.48912	77.94604	130	52.054
5	83.68464	0.694721	83.68753	130	46.312
6	62.00851	3.712042	62.11952	65	2.88
7	70.28992	-10.8374	71.12047	90	18.88
8	-13.5793	16.69032	21.51658	70	48.483
9	**36.96798**	**-5.97669**	**37.448**	**130**	**92.552**
10	30.17616	-28.8131	41.72287	45	3.277
11	27.17178	9.291649	28.71655	65	36.283
12	15.27643	9.913747	18.21131	32	13.789
13	-1.4E-15	-22.8755	22.87547	65	42.125
14	27.17178	30.457	40.81586	65	24.184
15	43.89995	11.27718	45.32527	65	19.675
16	-2.1E-15	-23.2184	23.21839	65	41.782
17	7.991365	3.502738	8.725313	32	23.275
18	17.60197	11.06044	20.78852	32	11.211
19	7.106615	7.225328	10.13456	32	21.865
20	1.69431	1.700979	2.400837	16	13.599
21	3.506098	5.213975	6.283172	16	9.717
22	6.174126	3.739478	7.218278	16	8.782
23	2.913157	2.714976	3.982158	16	12.018
24	-6.59829	-0.70817	6.636184	32	25.364
25	8.900285	1.631925	9.04866	32	22.951
26	5.540297	0.697752	5.584062	32	26.416
27	15.06389	10.33336	18.26743	32	13.733
28	7.143737	4.809001	8.611589	32	23.388
29	-2.56472	-1.14343	2.808063	32	29.192
30	4.612154	5.925935	7.509239	16	8.491
31	4.51827	3.540338	5.740101	16	10.26
32	1.350488	4.201369	4.413085	16	11.587
33	-2.90354	-2.7639	4.008699	16	11.991
34	3.552546	2.378488	4.275252	16	11.725
35	-6.49149	-5.20422	8.320059	16	7.68
36	19.90046	10.67213	22.58147	65	42.419
37	6.208187	1.704005	6.437797	16	9.562
38	7.115281	1.705838	7.316906	16	8.683
39	3.709306	0.617174	3.7603	16	12.24
40	-0.03056	5.734084	5.734165	32	26.266
41	20.02898	2.470865	20.18081	32	11.819

Table.9. Power system losses in IEEE-30 bus system

Description	Value

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Active power loss (MW)	18.4039
Reactive power loss (MVAr)	58.0333

1) SVC analysis

In this section, the analysis of power system in the presence of SVC is presented. The SVC control parameters i.e. Q_{SVC} is varied from -25 MVAr to +25 MVAr in steps of 10 MVAr.

The variation of voltage magnitudes, line apparent power flows and system power losses are shown in Figs.11, 12 and 13.

From these figures it is identified that, because of placing SVC at bus 26, the voltage magnitude has major variation at bus 26. As Q_{SVC} is increased from negative value to the positive value i.e. from -0.25 p.u. to 0.25 p.u the voltage magnitude value is increased from its minimum value to maximum value.

Similarly, from Fig. 12, due to SVC at bus-26, the lines which are connected to 26th bus have considerable variation as the voltage has variations.

From Fig.13, it is identified that, active power losses are minimum when SVC is at 0.05 p.u. and maximum when SVC is at -0.25 p.u.

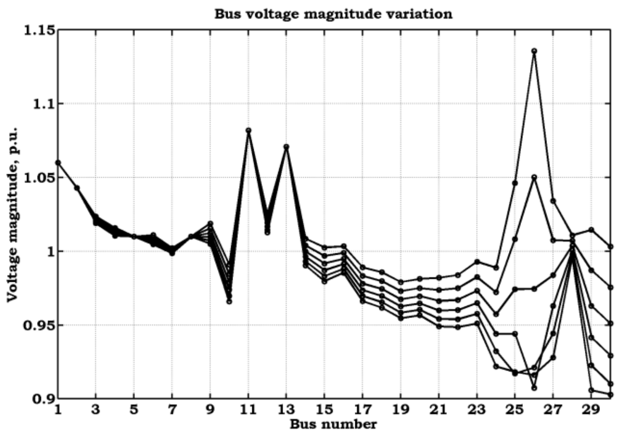

Fig.11. Variation of bus voltage magnitude with SVC for IEEE-30 bus system

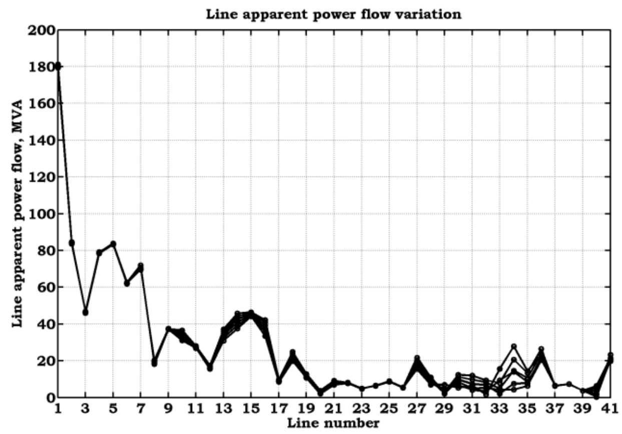

Fig.12. Variation of line apparent power flow with SVC for IEEE-30 bus system

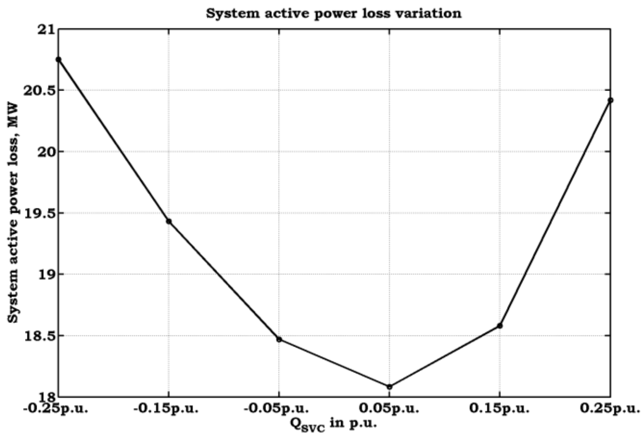

Fig.13. Variation of system active power loss with SVC for IEEE-30 bus system

2) TCSC analysis

In the similar way, the variation of bus voltage magnitudes, line apparent power flows and system power losses in the presence of TCSC are shown in Figs. 14, 15 and 16. Here, the TCSC control parameter X_{TCSC} is varied from -0.8Xline to 0.2 Xline. i.e. from -0.0656 p.u. to 0.0144 p.u. in steps of 0.02 p.u.

Similarly, the variation of voltage magnitudes, line apparent power flows and system power losses are shown in Figs.14, 15 and 16.

From these figures it is identified that, because of placing TCSC in line-9, there is no significant voltage magnitude variation is observed as it is a series device.

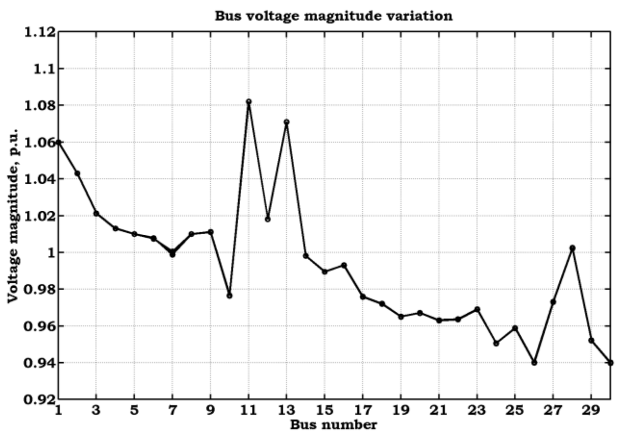

Fig.14. Variation of bus voltage magnitude with TCSC for IEEE-30 bus system

Similarly, from Fig. 15, due to TCSC in line-9, the TCSC connected line (9th line) and the lines which are connected to buses 6 and 7 have considerable variation.

From Fig.16, it is identified that, active power losses are decreased as X_{TCSC} is increased from its minimum value to maximum value.

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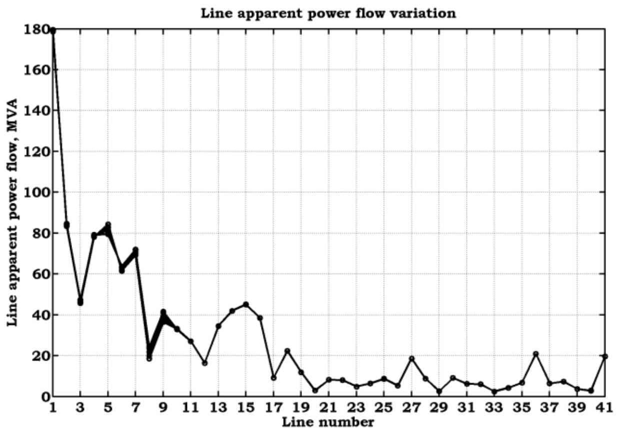

Fig.15. Variation of line apparent power flow with TCSC for IEEE-30 bus system

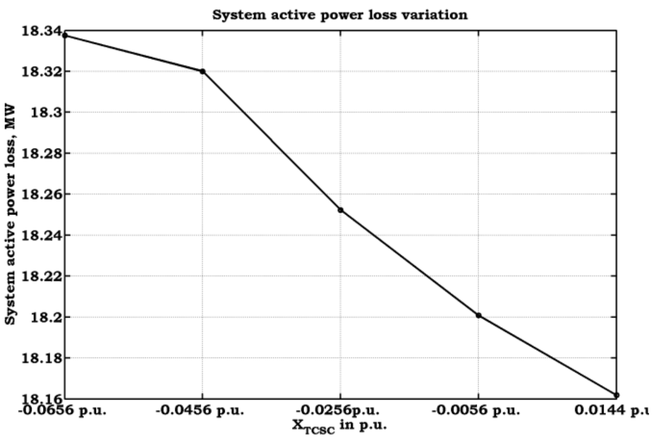

Fig.16. Variation of system active power loss with TCSC for IEEE-30 bus system

VI. CONCLUSION

In this paper, the effect of FACTS controllers such as SVC and TCSC are analyzed on a given power system. A methodology to install SVC and TCSC has been presented. The device control parameters such as Q_{SVC} and X_{TCSC} are varied within its limits and the variation of the system parameters such as bus voltage magnitude; transmission line apparent power flows and system active power losses are analyzed. The proposed methodology is tested on standard HALE and IEEE-30 bus test systems. From this analysis, it is concluded that, the proposed methodology has a significant effect to analyze the effect of device control parameters on the system parameters.

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