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Comparison of SVC and TCSC for Enhancing Static Voltage Stability on Weak Buses of Indian Utility 69 Bus System

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Abstract - The purpose of this project is to study the reactive power sensitivity as an index for finding out the weakest bus. This work presents a comparison of FACTS devices for static voltage stability study. Various performance measures including PV and QV curves, voltage profiles, and power losses are compared. Placement of TCSC and SVC are proposed for loading margin enhancement. One way to increase the transmission capacity of the system without operating it to its thermal stability limit is to provide reactive power compensation at various locations. Reactive power compensation improves the voltage profile of the system, increase the power transfer in the lines and reduce losses. The work provides a guide for utilities to have an appropriate choice of FACTS device for enhancing loading margin and static voltage stability. Voltage Collapse point is also determined from the P-V and Q-V curves of the weak bus. The way of finding out Voltage Stability Margin is also proposed. Finally, a method to compensate the reactive power of the weakest bus to improve its stability is also proposed. These techniques are tested on the Indian utility 69 bus system and results are given to prove the effectiveness of the proposed methods.

Keywords: voltage stability, weak bus analysis, SVC, TCSC, voltage stability margin.

I. INTRODUCTION

The increase in power demand and limited sources for electric power is one of the main consideration has resulted in an interruption and instability in interconnected system. Voltage instability is mainly associated with reactive power imbalance. The load ability of a bus in the power system depends on the reactive power support that the bus can receive from the system as the system approaches the voltage collapse point or maximum loading point (MLP). Voltage collapse phenomena in power systems have become one of the important concerns in the power industry over the last two decades. Hence, the ability to determine voltage stability before voltage collapse has received a great attention. 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.

FACTS devices available for this purpose, namely, Static Var Compensator (SVC), Thyristor-Controlled Series Capacitor (TCSC) have been included in the problem formulation.

'Voltage stability' is concerned with the ability of power system to maintain the steady acceptable voltages at all system buses under normal conditions as well as when the system is being subjected to a disturbance. Power system is voltage stable if voltages after a disturbance are close to voltages at normal operating condition. A power system becomes unstable when voltage uncontrollably decreases due to outage of equipment, increment of load, decrement of production. Static analysis involves only the solution of algebraic equations and hence is computationally less extensive than dynamic analysis. Static voltage stability is ideal for the bulk of studies in which voltage stability limit for many cases must be determined.

The investigation reveals that it is possible to identify the weakest load bus in any multi bus system and it is possible to compute the voltage stability margin at that load bus using the developed technique. Compensation is also done by connecting FACTS controller with the weakest bus.

II. SYSTEM MODEL

A. System Network

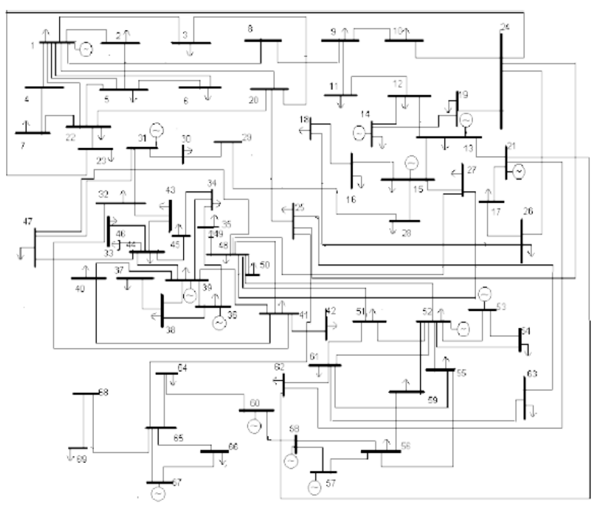

Fig. 2.1 Indian 69 bus utility system

Indian data 69 bus utility system data are taken from planning wings report of Tamil Nadu electricity board (2004) are considered for analysis. The network is shown in figure 2.1. In large-scale power flow studies the Newton–Raphson method has proved most successful owing to its strong convergence characteristics [1].

B. Dtetermination of Weakest BUS

Newton Raphson Load Flow Method is applied on this system.

$$\underbrace{\begin{bmatrix}\Delta P\\ \Delta Q\end{bmatrix}^{(i)}}_{F(x^{(i-1)})} = -\underbrace{\begin{bmatrix}\frac{\partial P}{\partial \theta} & \frac{\partial P}{\partial v}V\\ \frac{\partial Q}{\partial \theta} & \frac{\partial y}{\partial x}V\end{bmatrix}^{(i)}}_{J(x^{(i-1)})}\underbrace{\begin{bmatrix}\Delta\theta\\ \frac{\Delta V}{V}\end{bmatrix}^{i}}_{\Delta x^{1}} \qquad (1)$$

Equation (1) represent Jacobian matrix (J) which can be subdivided into four sub matrices- J= [J1 J2; J3 J4]. Now, the reactive power is less sensitive to changes in phase angles and is mainly dependent on changes in voltage magnitudes. Similarly, real power change is less sensitive to the change in the voltage magnitude and is most sensitive to the change in phase angle. So, it is quite accurate to set J2 and J3 of the Jacobian matrix to zero. The diagonal elements of J4 indicate the reactive power sensitivity of i-th bus. $\partial Qi/\partial|Vi|$ also indicates the degree of weakness for the i-th bus. The bus corresponding to the maximum value of $\partial Qi/\partial|Vi|$ is the strongest bus and the bus corresponding to the minimum value of $\partial Qi/\partial|Vi|$ is the weakest bus [2]. Weakest load bus of any multi bus interconnected system can be found out by this process.

Table 1. Diagonal element of jaccobian (j4) matrix

Load bus no	Diagonal element	Syetem bus no.
1 (slack bus)	———	1
2	462.325	2
3	70.85	3
4	117.57	5
5	24.25	6
6	136.90	7
7	29.153	8
8	54.004	9
9	56.705	10
10	44.172	11
11	127.657	12
12	412.318	13
13	120.038	14
14	375.311	15
15	312.5896	16
16	35.56	17
17	352.64	18
18	63.93	19
19	404.668	21
20	319.551	22
21	302.928	23
22	477.092	26
23	18.468	27
24	60.751	28
25	34.1304	29
26	42.87	30
27	88.9962	31
28	140.7605	32
29	139.1715	33
30	166.59	34
31	113.805	35
32	237.839	36
33	148.7629	37
34	306.3107	38
35	261.5	39
36	39.204	40
37	251.0363	41
38	82.279	42
39	52.0227	43
40	388.627	44
41	81.7094	45
42	45.6495	46
43	60.4588	47
44	571.8386	48
45	18.2340	49
46	11.8847	50
47	146.67	51
48	595.51	52
49	196.033	54
50	50.1535	55
51	89.3864	56
52	63.137	59
53	207.6270	61
54	265.58	62
55	118.6360	63
56	60.9591	64
57	310.1208	66
58	115.7846	68
59	34.4760	69

So, for Indian utility 69 bus system the weakest bus is 50th bus and the next six weakest bus is 6th, 8th, 27th, 29th, 49th and 69th bus without the connection of any FACTS controller.

C. ANALYSIS OF P-V AND Q-V CURVE

P-V curve analysis is use to determine voltage stability of a radial system and also a large meshed network [2][3][4]. For this analysis P i.e. power at a particular area is increased in steps and voltage (V) is observed at some critical load buses and then curves for those particular buses will be plotted to determine the voltage stability of a system by static analysis approach. To explain P-V curve analysis let us assume two-bus system with a single generator, single transmission line and a load, as shown in Figure 1.

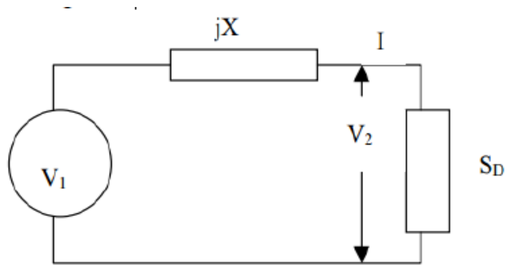

Figure 2.2 Two bus representation model

P-V curves are useful in deriving how much load shedding should be done to establish prefault network conditions even with the maximum increase of reactive power supply from various automatic switching of capacitors or condensers.

Here, the complex load assume is $S_{12} = P_{12} + jQ_{12}$ with V_1 is the sending end voltage and V_2 is receiving end voltage and cosθ is load power factor

$$S_{12} = P_{12} + jQ_{12} \quad (2)$$

$$S_D = P_D + jQ_D = -(P_{21} + jQ_{21}) \quad (3)$$

$P_D = -P_{21}$

$Q_D = -Q_{21}$

Where

$\theta_{12} = \theta_1 - \theta_2,$

$$P_D = |V_1||V_2|B \sin\theta_{12} \quad (4)$$

$$Q_D = -|V_2|^2B + |V_1||V_2|B \cos\theta_{12} \quad (5)$$

$\beta = \tan \emptyset,$

Now

$$Q_D = P_D\beta = -|V_2|^2B + |V_1||V_2|B\cos(\theta_{12}) \quad (6)$$

Equating the expression for P_D and Q_D, We have

$$(|V_2|^2)^2 + \left[\frac{2P_D\beta}{B} - |V_2|^2 + \frac{P_D}{B^2}[1+\beta^2]\right] = 0 \quad (7)$$

This is a quadratic equation in $|V_2|^2$,Eliminating θ_{12} and solving the second order equation ,we get

$$|V_2|^2 = \frac{1-\beta P_D \pm \sqrt{1-P_D(P_D+2\beta)}}{2} \quad (8)$$

As seen from equation, the voltage at the load point is influenced by the power delivered to the load, the reactance of the line, and the power factor of the load. The voltage has two solutions; the higher one is the stable solution. The load at which the two solutions have one value indicates the steady state voltage collapse point. Using this equation we have plotted P-V curve using MATLAB program for various power factors, lagging as well as leading as shown in fig.2.3

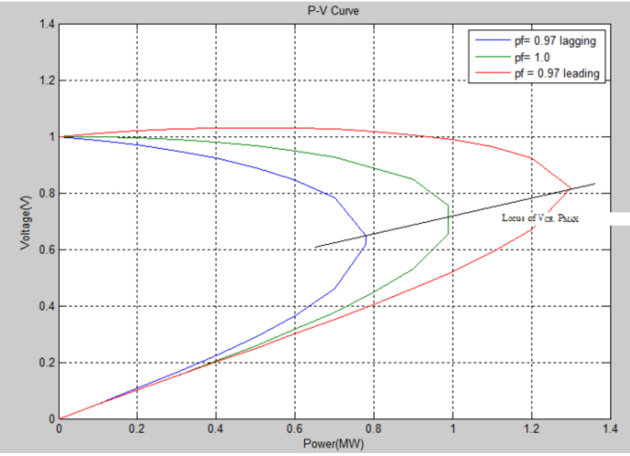

Fig. 2.3 P-V cuve using MATLAB program

The dotted line can be shown by connecting nose points of the P-V curve. Only the operating points above the critical points represent satisfactory operating condition. At the knee of the P-V curve, the voltage drops rapidly with the increase in loads. P-V curves are useful for conceptual analysis of voltage stability especially for radial systems.

Q-V curve is the relationship between the reactive power support (Q) and receiving end voltage (V_2) for different values of active power P.

We consider our simple (lossless) system again, with the equations,

$$P_D = |V_1||V_2|B \sin\theta_{12} \quad (9)$$

$$Q_D = -|V_2|^2B + |V_1||V_2|B \cos\theta_{12} \quad (10)$$

Now, again assume that V_1=1.0, and for a given value of PD and V_2, compute θ_{12} from the first equation, and then Q from thesecond equation. Repeat for various values of V_2 to obtain a Q-V curve for the specified real load PD. The Q-V curve can be obtained from the P-V curve as shown in figure 2.3.

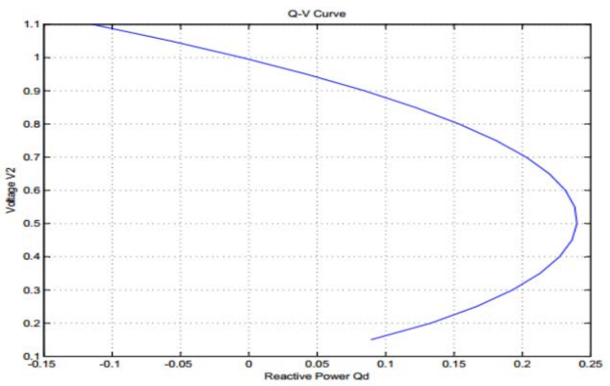

Fig. 2.4 Q-V curve analysis using MATLAB program.

One of the information that can be accessed from the curves is the sensitivity of the loads to the reactive power sources.

Thus P-V curve play a measure role in understanding and explaining voltage stability. However, it is not necessarily the most efficient way of studying voltage stability since it requires a lot of computations for large complex networks.

"Voltage Stability Margin" of a power system is a measure to estimate the available power transfer capacity, net power transfer capacity or total power transfer capacity. Voltage stability margin (VSM) is the measure of the security level of the bus, if the value VSM is high then the bus is more secured and vice versa. Voltage stability margin (VSM) is a straightforward, widely accepted and easily understood index of voltage collapse. This is a difference or a ratio between the operation and voltage collapse points according to a key parameter (loading, line flow, etc).So, voltage stability margin can be calculated in the following manner-

$$VSM=\frac{V_{w(base)}-V_{w(critical)}}{V_{w(critical)}} \quad (11)$$

In equation, $V_{W\ (base)}$ = bus voltage of the weakest bus of the system at normal operating condition. $V_{W\ (critical)}$ = bus voltage of the weakest bus of the system at voltage collapse point.

III. PREVIOUS WORK

So far, many power system blackouts caused by voltage instability around the world have been reported [5], which lead to the serious consequences on society and economy. There exist different viewpoints with respect to voltage collapse and determination of voltage stability index [6]. Voltage change margin index was used to judge power system voltage stability weak buses [7]; Zhang Yao and Song Wennan [8] proposed active power margin index considering the close relationship between active power load and voltage; Yuan-Lin Chen [9] thought that the voltage mainly influenced by reactive power, and defined the voltage collapse proximity indicator (VCPI) for identifying the weakest bus; The sensitivity index between voltage and active power load was presented in [10]; The singular value was proposed to analyse the weak bus [11]; The modal analysis technique was chosen to identify the system weak buses [12].

IV. PROPOSED METHODOLOGY

Now, the voltage collapse point is to be determined, P is increased by keeping Q constant and P-V curve is plotted for the weakest and next weakest bus. Also Q is increased keeping P constant and Q-V curve is plotted for the weakest bus and next weakest bus. Analysis was performed on weak buses of system by series facts controller (TCSC) and parallel facts controller (SVC). The P-V and Q-V curve of the weakest and next weakest bus is shown in the fig. 4.1, fig. 4.2, fig. 4.3, fig. 4.4, fig. 4.5, fig. 4.6.

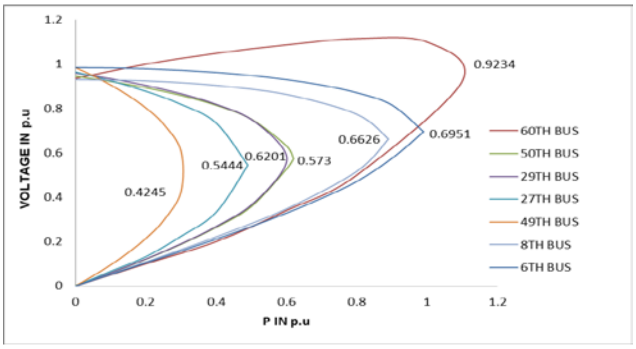

Fig. 4.1 P-V curve without compensation

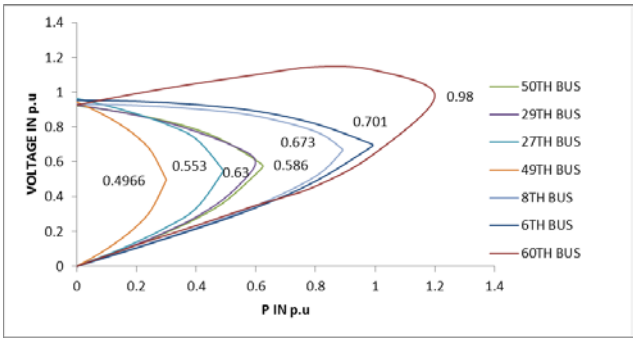

Fig. 4.2 P-V curve with TCSC

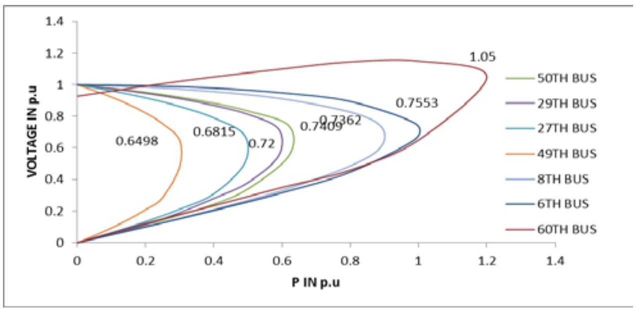

Fig. 4.3 P-V curve with SVC

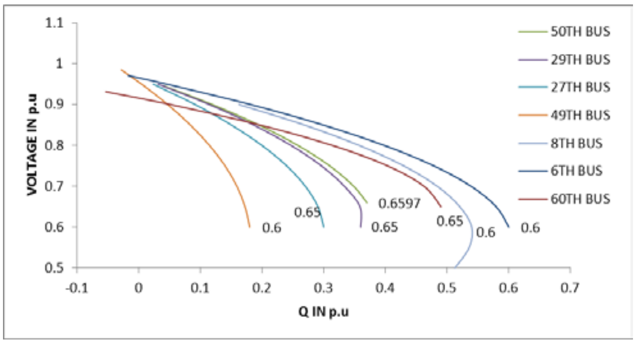

Fig. 4.4 Q-V curve without compensation

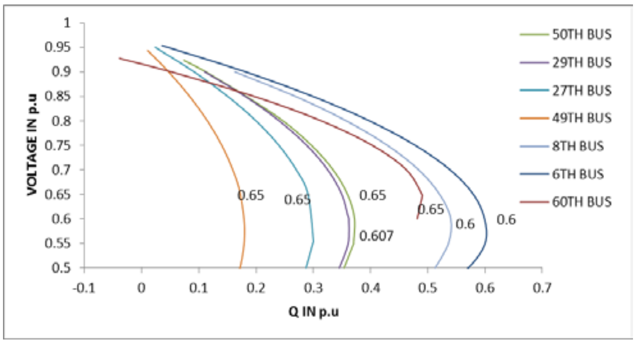

Fig. 4.5 Q-V curve with TCSC

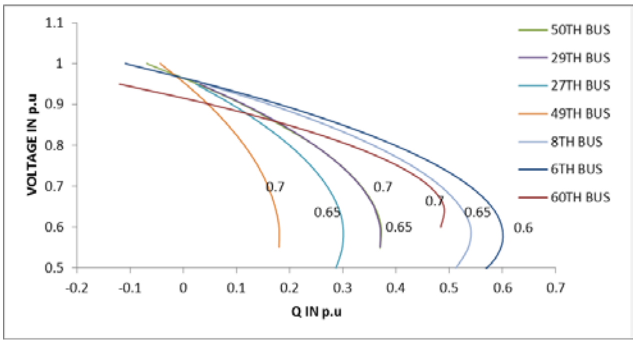

Fig. 4.6 Q-V curve with SVC

For Indian Utility 69 Bus System bus system the Voltage stability margin as obtained in our test is shown in the table 2.

V. SIMULATION/EXPERIMENTAL RESULTS

From P-V and Q-V curve , we obtain critical voltage ($V_{critical}$) and base voltage (Vbase). Calculate voltage stability margin (VSM) for all the seven weak bus and compare the value of VSM of base case and the system with SVC and TCSC.

TABLE 2. VOLTAGE STABILITY MARGIN OF BASE CASE AND SYSTEM WITH SVC AND TCSC

Bus no	VSM of base case		VSM with SVC		VSM with TCSC	
	VSM (P)	VSM (Q)	VSM (P)	VSM (Q)	VSM (P)	VSM (Q)
6	0.38	0.61	0.42	0.67	0.38	0.73
8	0.40	0.72	0.64	0.67	0.40	0.73
27	0.90	0.64	0.91	0.82	0.90	0.65
29	0.77	0.607	0.79	0.65	0.77	0.74
49	0.68	0.60	0.70	0.81	0.67	0.54
50	0.65	0.42	0.67	0.82	0.64	0.68
69	0.09	0.43	0.16	0.538	0.09	0.44

Now, voltage stability margin (VSM) is the measure of the security level of the bus, if the value of VSM is high then the bus is more secured and vice-versa [2].

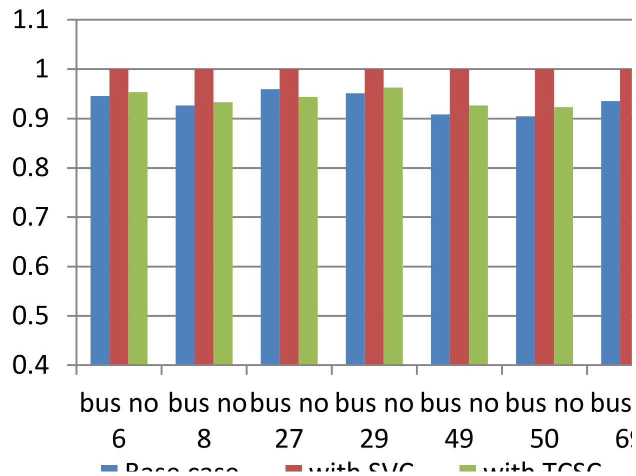

Fig. 5.1 Comparison of voltage magnitude of Base case and system with SVC and TCSC

Voltage magnitude has been compared from the solution of newton Raphson for base case and system with SVC and TCSC. The comparison is given in Figure 4.1.

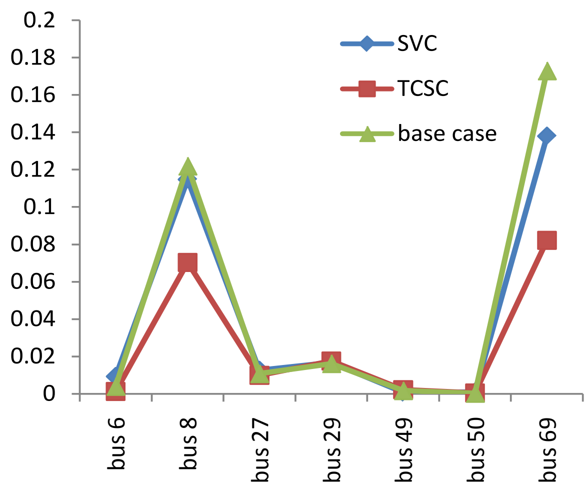

Fig 5.2. Reactive power losses of Base case and system with SVC and TCSC for all weak buses.

Major contributory factors to voltage instability are power system configuration, generation pattern and load pattern Power system network can be modified to alleviate voltage instability or collapse by adding reactive power sources i.e. shunt capacitors and/or Flexible AC Transmission System (FACTS) devices at the appropriate locations. Reactive power losses has been compared for all weak busses before and after incorporating FACTS controller.

Placing appropriate FACTS device at suitable location with proper sizes would lead to maximum loading margin. According to these, it would be useful to study and compare the well-kown FACTS devices and Load margin after and before incorporating FACTS devices.

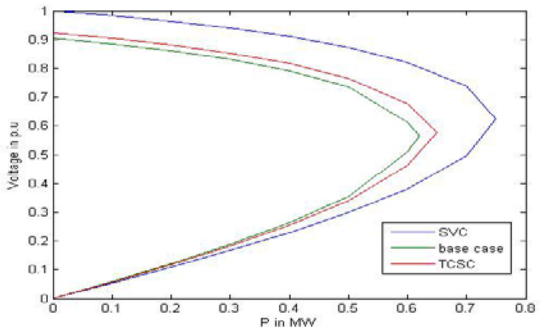

Fig 5.3 Load margin of base case and system with SVC and TCSC

VI. CONCLUSION

Power flow study determines the best operating condition of a Power System Network. Newton- Raphson load flow method has been used for solving the power-flow equation. To study the effect of TCSC and SVC on power system, a modified power flow model of the TCSC and SVC is attempted. TCSC and SVC is placed at the weak bus locations in 69 bus systems and the modified load flow program is used to access the effect of TCSC and SVC on the system. The simulation is done using MATLAB.

Load flow study of Indian utility 69 bus system is considered and it is shown that the voltage profile of the system is improved and it is shown using plots. It was also evident that the voltage magnitude of that particular bus at which SVC is placed is maintained at 1 p.u. The reactive power losses of the weak bus is reduced. The reactive power loss in case of TCSC is less than SVC and base case.

Load margin in case of SVC is greater than TCSC and SVC. The buses placed far away from the SVC and TCSC are least effected.

VII. FUTURE SCOPES

The completion of one research project opens the avenues for work in many other related areas. The following areas are identified for future work:

- The load flow study can be done on larger interconnected power system like IEEE 118 bus and even larger
- UPFC, IPFC and other FACTS controller can also be incorporated along with the STATCOM and their effect on the system can be studied
- Optimal location of STATCOM can be found out using Genetic Algorithm and fuzzy logic
- Economic Assessment of FACTS devices against other methods can be studied.

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