International Journal of Engineering Research in Electrical and Electronic Engineering (IJEREEE) Vol 1, Issue 8, October 2015

Evaluation of Available Transfer Capability using SVC and TCSC

[1]M Venkateswara Rao, [2] Sirigiri Sivanagaraju,
[1]Associate Professor in PE, GMR Institute of Technology, Rajam, Srikakulam, Andhra Pradesh, India ,
[2] Professor in EEE, UCEK, Kakinada, JNTUK, Kakinada, Andhra Pradesh, India,
[1]mvrmvrmvr@gmail.com,[2]sirigiri70@yahoo.co.in,

***Abstract*— The world aims at creating a competitive market to trade electricity, which generates a host of new technical challenges for market participants and power system researchers. Efficient capacity expansion planning, cost minimization, more choice and better services are possible in deregulated markets. One of the major challenges for power system operators to accurately estimate the transfer capability beyond the committed usage. In order to evaluate the ATC, the FACTS devices i.e. SVC and TCSC is used and it is observed that, the series device TCSC is giving a promising strategy than SVC. The proposed methodology is tested on IEEE-30 bus system.**

***Index Terms*—** ATC; Bi-lateral Transaction; ACPTDF; Power Injection model of TCSC & SVC

I. INTRODUCTION

The power flow sensitivity based methods are proposed by many authors to evaluate ATC, for any power system networks. Evaluation of ATC using DC load flow approach has been presented in [1].However the more accurate methods based on AC load flow approach using sensitivity factors are well reported in [2-7]. To calculate PTDFs for ATC enhancement a methodology is proposed to determine reactance of TCSC is presented in [8]. Based on the literature available, it is observed that the role of FACTS devices is most influencing in the calculations of ATC through ACPTDF method [9]. The steady state power flow control using FACTS devices proved that, the performance has been considerably increased in the power system networks [10-13]. It is very much important to determine the optimal location for placement of FACTS devices, in view of their considerable installation costs. Many authors have addressed ATC enhancement using FACTS devices in [14-15].

II. ACPTDF DETERMINATION

From the power transfer point of view, a transaction is a specific amount of power that is injected into the system at one bus by a generator and drawn at another bus by a load. The coefficient of linear relationship between the amount of a transaction and flow on a line is represented by ptdf. It is also called sensitivity because It Relates The Amount Of One Change - Transaction Amount - to another change - line power flow.

Ptdf Is The Fraction Of Amount Of A Transaction From One Bus To Another That Flows Over A transmission line $PTDF_{lm,ji}$ is the fraction of a transaction from bus i to bus j that flows over a transmission line connecting buses l and m.

$$PTDF_{lm,ji} = \frac{\Delta P_{lm}}{P_{ji}}$$

A.Atc calculation

Atc is determined by recognizing the new flow on the line from node i to node m, due to a transaction from node i to node j. The new flow on the line is the sum of original flow P_{lm}^0

$$P_{lm} = P_{lm}^0 + PTDF_{lm,ij} P_{ij}$$

Where, P_{lm}^0 is the base case flow on the line and P_{ji} is the magnitude of proposed transfer. If the limit on line im, the maximum power that can be transferred without overloading line im, is $P_{lm}^{\max}$, then,

$$P_{ij,lm}^{\max} = \frac{P_{lm}^{\max} - P_{lm}^0}{PTDF_{lm,ij}}$$

$P_{ij,lm}^{\max}$ is the maximum allowable transaction from node i to node j constrained by the line from node I to node m. Atc is the minimum of the maximum allowable transactions over all lines. Using the above equation, any proposed transaction for a specific hour may be checked by calculating atc. If it is greater than the amount of the proposed transaction, the transaction is allowed. If not, the transaction must be rejected or limited to the atc.

$$ATC_{ij} = \min\left(P_{ij,lm}^{\max}\right)$$

using the above equation, any proposed transaction for a specific hour may be checked by calculating atc. if it is greater than the amount of the proposed transaction, the transaction is allowed. if not, the transaction must be rejected or limited to the atc. the detailed analysis regarding the calculations of atc values for any power system network has been given in [15].

B.Operating Principle of TCSC

TCSC is one of the series compensator; it can capable to control power flow in line, damping power oscillations. Basic simple TCSC model is shown in Fig.1.TCSC is formed by connecting the capacitor in series with the transmission line and thyristor-controlled reactor (TCR) in parallel with capacitor. TCSC is simple construction and less cost compared to other series FACTS devices. Power transfer in the lines can be controlled by controlling the net series impedance of the line.

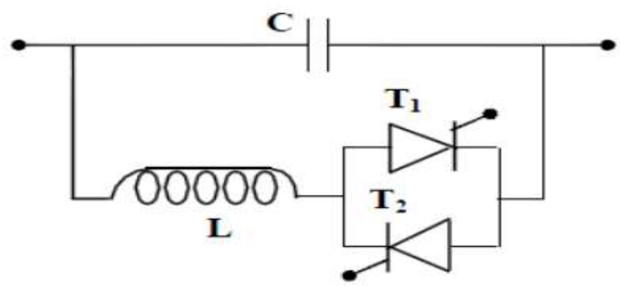

Fig. 1 Model of TCSC

A simple transmission system represented π equivalent parameters connected between bus-k and bus-m. The real and reactive power flows from bus-k to bus-m can be written as

$$P_{km} = V_k^2 G_{km} - V_k V_m \left[G_{km} Cos(\delta_{km}) + B_{km} Sin(\delta_{km}) \right] \quad (1)$$

$$Q_{km} = -V_k^2 (B_{km} + B_{sh}) - V_k V_m \left[G_{km} Sin(\delta_{km}) - B_{km} Cos(\delta_{km}) \right] \quad (2)$$

Where $\delta_{km} = \delta_k - \delta_m = -\delta_{mk}$

The real and reactive power flows from bus-m to bus-k is

$$P_{mk} = V_m^2 G_{km} - V_k V_m \left[G_{km} Cos(\delta_{km}) - B_{km} Sin(\delta_{km}) \right] \quad (3)$$

$$Q_{mk} = -V_m^2 (B_{km} + B_{sh}) + V_k V_m \left[G_{km} Sin(\delta_{km}) + B_{km} Cos(\delta_{km}) \right] \quad (4)$$

C. Power Injection 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.

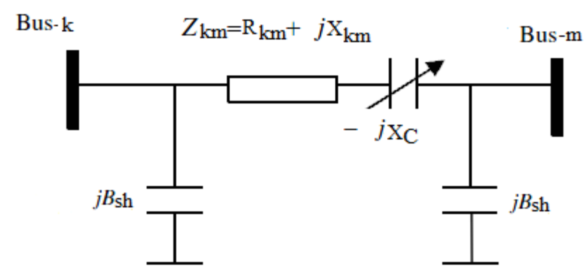

Fig.2 Transmission line with TCSC

The line data will be modified by placing TCSC in series with line. A new line reactance is given as follows

$$X_{km\,new} = X_{km} - X_C \quad (5)$$

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

$$Y_{km}^{'} = \frac{1}{Z_{km}^{'}} = \frac{1}{R_{km} + j(X_{km} - X_C)} \quad (6)$$

$$Y_{km}^{'} = G_{km}^{'} + jB_{km}^{'} = \frac{R_{km} - j(X_{km} - X_C)}{R_{km}^2 + (X_{km} - X_C)^2} \quad (7)$$

$$G_{km}^{'} = \frac{R_{km}}{R_{km}^2 + (X_{km} - X_C)^2} \quad (8)$$

$$B_{km}^{'} = -\frac{(X_{km} - X_C)}{R_{km}^2 + (X_{km} - X_C)^2} \quad (9)$$

The modified active and reactive power flows from bus-k to bus-m, and from bus-m to bus-k of a line having series impedance and a series reactance are

$$P_{km}^{TCSC} = V_k^2 G_{km}^{'} - V_k V_m \left(G_{km}^{'} Cos(\delta_{km}) + B_{km}^{'} Sin(\delta_{km}) \right) \quad (10)$$

$$Q_{km}^{TCSC} = -V_k^2 \left(B_{km}^{'} + B_{sh} \right) - V_k V_m \left(G_{km}^{'} Sin(\delta_{km}) - B_{km}^{'} Cos(\delta_{km}) \right) \quad (11)$$

$$P_{mk}^{TCSC} = V_m^2 G_{km}^{'} - V_k V_m \left(G_{km}^{'} Cos(\delta_{km}) - B_{km}^{'} Sin(\delta_{km}) \right) \quad (12)$$

$$Q_{mk}^{TCSC} = -V_m^2 \left(B_{km}^{'} + B_{sh} \right) + V_k V_m \left(G_{km}^{'} Sin(\delta_{km}) + B_{km}^{'} Cos(\delta_{km}) \right) \quad (13)$$

The power loss in the line with TCSC can be written as

$$P_{Loss} = P_{km}^{TCSC} + P_{mk}^{TCSC} = G_{km}^{'} \left(V_k^2 + V_m^2 \right) - 2 V_k V_m G_{km}^{'} Cos(\delta_{km}) \quad (14)$$

$$Q_{Loss} = Q_{km}^{TCSC} + Q_{mk}^{TCSC} = -\left(V_k^2 + V_m^2 \right)\left(B_{km}^{'} + B_{sh} \right) + 2 V_k V_m B_{km}^{'} Cos(\delta_{km}) \quad (15)$$

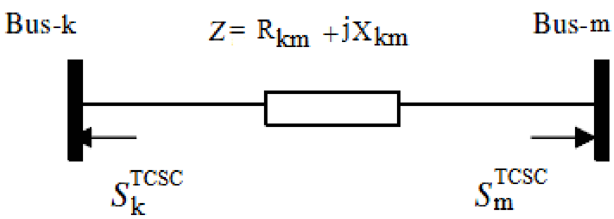

Fig.3 Power injection model of TCSC

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

$$P_k^{TCSC} = P_{km} - P_{km}^{TCSC} = V_k^2 \Delta G_{km} - V_k V_m \left[\Delta G_{km} Cos(\delta_{km}) + \Delta B_{km} Sin(\delta_{km}) \right] \quad (16)$$

$$P_m^{TCSC} = P_{mk} - P_{mk}^{TCSC} = V_m^2 \Delta G_{km} - V_k V_m \left[\Delta G_{km} Cos(\delta_{km}) - \Delta B_{km} Sin(\delta_{km}) \right] \quad (17)$$

$$Q_k^{TCSC} = Q_{km} - Q_{km}^{TCSC} = -V_k^2 \Delta B_{km} - V_k V_m \left[\Delta G_{km} Sin(\delta_{km}) - \Delta B_{km} Cos(\delta_{km}) \right] \quad (18)$$

$$Q_m^{TCSC} = Q_{mk} - Q_{mk}^{TCSC} = -V_m^2 \Delta B_{km} + V_k V_m \left[\Delta G_{km} Sin(\delta_{km}) + \Delta B_{km} Cos(\delta_{km}) \right] \quad (19)$$

Where

$$\Delta G_{km} = \frac{X_C R_{km} \left(X_C - 2 X_{km} \right)}{\left(R_{km}^2 + X_{km}^2 \right)\left(R_{km}^2 + \left(X_{km} - X_C \right)^2 \right)} \quad (20)$$

$$\Delta B_{km} = \frac{-X_C \left(R_{km}^2 - X_{km}^2 + X_C X_{km} \right)}{\left(R_{km}^2 + X_{km}^2 \right)\left(R_{km}^2 + \left(X_{km} - X_C \right)^2 \right)} \quad (21)$$

TCSC device is modelled with power injection model so far by using the TCSC control variable. It is possible to calculate the complex power injected S_k^{TCSC} and S_m^{TCSC} at bus-k and bus-m respectively.

$$S_k^{TCSC} = P_k^{TCSC} + j Q_k^{TCSC} \quad (22)$$

$$S_m^{TCSC} = P_m^{TCSC} + j Q_m^{TCSC} \quad (23)$$

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

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} H_{new} & M_{new} \\ N_{new} & L_{new} \end{bmatrix} . \begin{bmatrix} \Delta\delta \\ \frac{\Delta V}{V} \end{bmatrix} \quad (24)$$

Where new mismatch vectors are

$$\Delta P_i = P_k^{spec} + P_k^{TCSC} - P_k^{calc} \quad (25)$$

$$\Delta Q_i = Q_k^{spec} + Q_k^{TCSC} - Q_k^{calc} \quad (26)$$

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

$$H_{new} = H + \frac{\partial P^{TCSC}}{\partial \delta} \; ; \; M_{new} = M + \frac{\partial P^{TCSC}}{\partial V} V \quad (27)$$

$$N_{new} = N + \frac{\partial Q^{TCSC}}{\partial \delta} \; ; \; L_{new} = L + \frac{\partial Q^{TCSC}}{\partial V} V \quad (28)$$

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

D.Static Var Compensator (SVC)

The IEEE definition of the SVC is as follows: "A shunt connected static VAr generator or absorber whose output is adjusted to exchange capacitive or inductive current so as to maintain or control specific parameters of the electrical power system (typically bus voltage)."

SVCs are used in a given power systems to enhance the voltage levels so that system stability has been improved.

E.Modeling of SVC

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. With reference to Fig. 4, the current drawn by the SVC is

$$I_{SVC} = jB_{SVC}V_i \qquad (29)$$

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

$$Q_{SVC} = Q_i = -V_i^2 B_{SVC} \qquad (30)$$

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. In this paper, SVC is modeled as an ideal reactive power injection at bus-i shown in Fig.4.

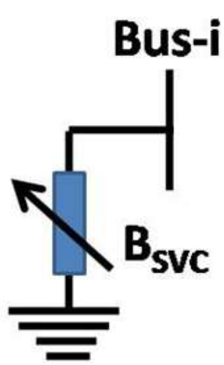

Fig.4. Power injection model of SVC

III. ACPTDF DETERMINATION WITH FACTS DEVICES

If a change in the transmission line quantity is ΔP_{ij} for a transaction of P_{mn} among the seller and buyer bus with FACTS, the ACPTDF can be calculated as

$$ACPTDF_{mn,FACTS}^{ij} = \frac{\Delta P_{ij}^{\text{FACTS}}}{P_{mn}} \qquad (31)$$

For PTDF calculations with FACTS, the power flow sensitivity and N-R load flow Jacobian matrix can be calculated. The change in power flow at any bus i can be formulated in terms of Jacobian as:

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} J_{1,\text{FACTS}} & J_{2,\text{FACTS}} \\ J_{3,\text{FACTS}} & J_{4,\text{FACTS}} \end{bmatrix} \begin{bmatrix} \Delta \delta \\ \Delta V \end{bmatrix} \qquad (32)$$

Where $J_{1,\text{FACTS}} = \frac{\partial P}{\partial \delta}$,

$$J_{2,\text{FACTS}} = \frac{\partial P}{\partial V}, J_{3,\text{FACTS}} = \frac{\partial Q}{\partial \delta}, J_{4,\text{FACTS}} = \frac{\partial Q}{\partial V} \qquad (33)$$

Based on these equations the change in the angle and voltage magnitudes can be determined. Based on the ACPTDF values, the best possible location of FACTS has been identified to evaluate the ATC values for possible transactions.

IV. RESULT AND DISCUSSION

The proposed ATC evaluation procedure is implemented on IEEE 30 Bus System by using SVC and TCSC at suitable locations. This test system is having six generators and forty one transmission lines. However out of thirty buses, the loads are connected to twenty one buses only. Since out of these one bus is taken as a slack bus (bus - 1), therefore the possible bi-lateral transactions for both the cases (i.e. with SVC & TCSC) with generator at bus -2 are listed in Table 1 and also variation of ATC values for possible bi-lateral transactions with generator at bus-2 is shown in Fig.5.

Similarly ATC values for possible bi-lateral transactions with generator at bus-5, 8, 11&13 are shown in Table.2, 3, 4&5 respectively. The corresponding variations of ATC with FACTS devices are represented in Fig.6, 7, 8 &9. It is also observed that, since SVC is a shunt device, the ATC values are marginally reduced in all the transactions but when the TCSC is used, the ATC values are enhanced in all the transactions. Hence it is evident that, the series FACTS devices will be useful in enhancing the power flow in any power transmission networks.

Table 1. ATC evaluation for possible bi-lateral transactions with generator at bus-2

S. No.	Transaction Details		ATC		
	Generator bus number	Load bus number	Without FACTS device	With SVC	With TCSC
1	2	3	121.0226	120.1475	121.5042
2		4	104.2924	103.0977	104.3477
3		5	123.0127	122.3934	123.8774
4		7	45.53516	45.30674	45.55606
5		8	26.79385	26.65625	26.87944
6		10	25.62739	25.09925	25.70357
7		12	71.27687	70.12049	71.87067
8		14	22.55846	22.43567	22.70769
9		15	20.63313	20.52346	20.77723
10		16	37.82207	37.13296	37.98318
11		17	22.73442	22.86455	23.94177
12		18	10.71314	10.35957	10.98517
13		19	9.335798	9.012899	9.422176
14		20	11.89237	11.33291	11.99032
15		21	12.72176	12.25815	12.98677
16		23	10.39978	10.13778	10.52607
17		24	11.53429	11.47662	11.81577
18		26	7.459279	7.131983	7.498455
19		29	8.924289	8.329668	9.130661
20		30	9.900268	9.130767	10.11473

Table 2. ATC evaluation for possible bi-lateral transactions with generator at bus-5

S. No.	Transaction Details		ATC		
	Generator bus number	Load bus number	Without FACTS device	With SVC	With TCSC
1	5	2	199.3174	198.1059	199.7518
2		3	144.7646	143.1812	144.8308
3		4	147.0735	146.4058	146.8358
4		7	45.45157	45.10525	45.55104
5		8	27.07453	26.69638	26.78608
6		10	26.67073	26.39524	26.48097
7		12	73.14996	72.46863	72.70225
8		14	22.67424	22.22504	22.29668
9		15	21.15746	21.02824	21.09544
10		16	38.60395	38.24994	38.37262
11		17	23.28306	23.02986	23.11379
12		18	10.79716	10.73611	10.76057
13		19	9.410203	9.349284	9.378295
14		20	12.01336	11.92331	11.95158
15		21	12.97692	12.89053	12.92191
16		23	19.48321	19.35201	19.42413
17		24	11.62149	11.54102	11.56807
18		26	7.476314	7.427121	7.490962
19		29	8.951354	8.592454	8.820036
20		30	9.925533	9.660223	9.912321

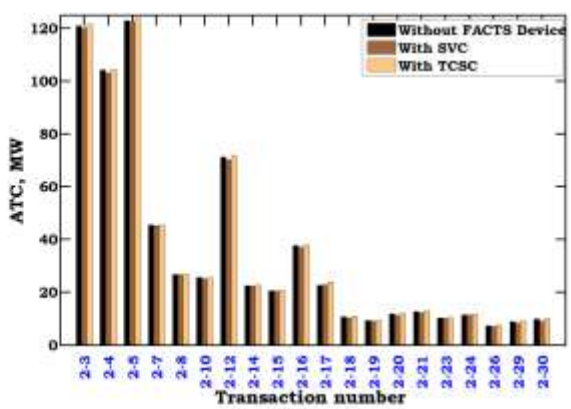

Fig.5. Variation of ATC values for possible bi-lateral transactions with generator at bus-2

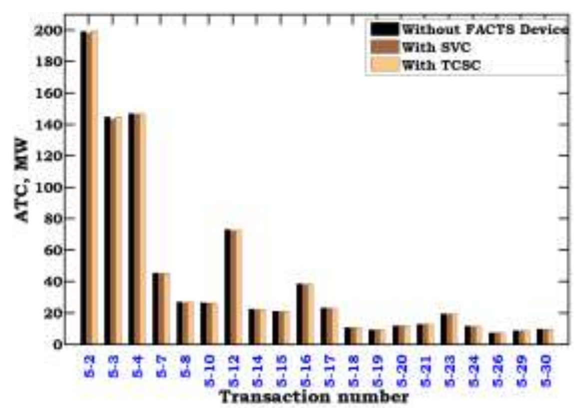

Fig.6. Variation of ATC values for possible bi-lateral transactions with generator at bus-5

Table 3. ATC evaluation for possible bi-lateral transactions with generator at bus-8

S. No.	Transaction Details		ATC		
	Generator bus number	Load bus number	Without FACTS device	With SVC	With TCSC
1	8	2	45.37419	44.94651	45.75345
2		3	49.79933	49.39287	49.83746
3		4	51.45711	51.02612	51.48502
4		5	45.84946	45.45762	45.86237
5		7	48.80121	48.36351	48.98823
6		10	28.23243	27.92499	28.67342
7		12	52.50883	52.03862	52.60344
8		14	22.86497	22.65457	22.95833
9		15	21.87428	21.67257	21.95778
10		16	39.54883	39.21221	39.73541
11		17	23.95097	23.73105	23.98483
12		18	10.90171	10.81616	10.94358
13		19	9.504393	9.421493	9.577355
14		20	12.16731	12.06367	12.66233
15		21	13.33502	13.21822	13.86728
16		23	10.61538	10.52456	10.91536
17		24	11.80904	11.70594	11.91738
18		26	7.512583	7.446723	7.913757
19		29	9.014172	8.935123	9.815754
20		30	9.984077	9.896523	9.997743

Table 4. ATC evaluation for possible bi-lateral transactions with generator at bus-11

S. No.	Transaction Details		ATC		
	Generator bus number	Load bus number	Without FACTS device	With SVC	With TCSC
1	11	2	42.93515	42.39178	42.97742
2		3	42.96768	42.42364	42.99395
3		4	42.97808	42.43456	42.79949
4		5	42.93976	42.39743	42.99134
5		7	42.98265	42.43838	42.72453
6		8	30.30812	29.92478	30.12632
7		10	41.25571	40.73365	41.00862
8		12	35.10306	34.65863	34.89735
9		14	23.50712	23.20963	23.36820
10		15	29.41206	29.03984	29.23556
11		16	42.99744	42.45363	42.73679
12		17	32.41835	32.00852	32.24532
13		18	11.84646	11.69637	11.77342
14		19	10.38229	10.25039	10.31932
15		20	13.64426	13.47174	13.56232
16		21	16.87937	16.66573	16.77672
17		23	11.08327	10.94275	11.01732
18		24	11.81592	11.66643	11.74804
19		26	7.500342	7.405474	7.455783
20		29	8.925488	8.812543	8.871924

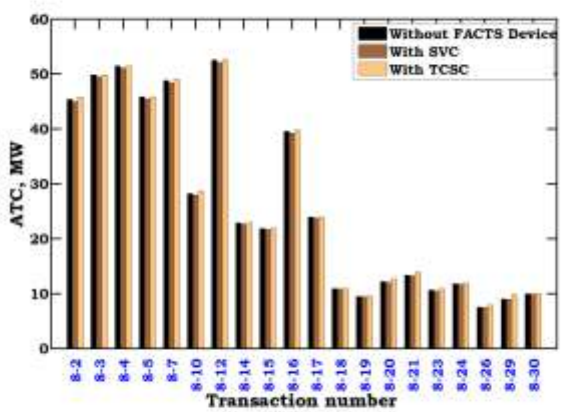

Fig.7. Variation of ATC values for possible bi-lateral transactions with generator at bus-8

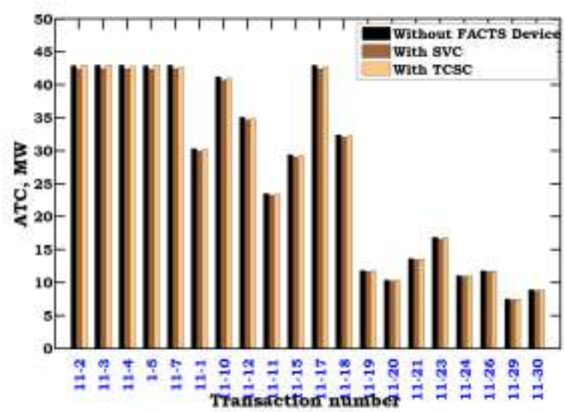

Fig.8. Variation of ATC values for possible bi-lateral transactions with generator at bus-11

Table 5. ATC evaluation for possible bi-lateral transactions with generator at bus-13

S. No.	Transaction Details		ATC		
	Generator bus number	Load bus number	Without FACTS device	With SVC	With TCSC
1		2	37.05011	36.82862	37.14593
2		3	37.07172	36.96016	37.14359
3		4	37.07966	36.96808	37.17554
4		5	37.05749	36.93898	37.14432
5		7	37.08627	36.96566	37.17617
6		8	30.84099	30.73996	30.91542
7		10	20.79596	20.72787	20.84713
8		12	37.01009	36.88803	37.09881
9		14	25.45671	25.37214	25.51867
10	13	15	15.90949	15.85721	15.94834
11		16	29.01607	28.92054	29.08428
12		17	17.08249	17.02632	17.12606
13		18	10.08673	10.05345	10.11409
14		19	8.832218	8.803263	8.852775
15		20	11.08711	11.05053	11.11579
16		21	11.40628	11.36864	11.43217
17		23	9.783025	9.750953	9.805694
18		24	11.41634	11.37823	11.44288
19		26	7.369722	7.345557	7.386797
20		29	8.760177	8.731442	8.780478

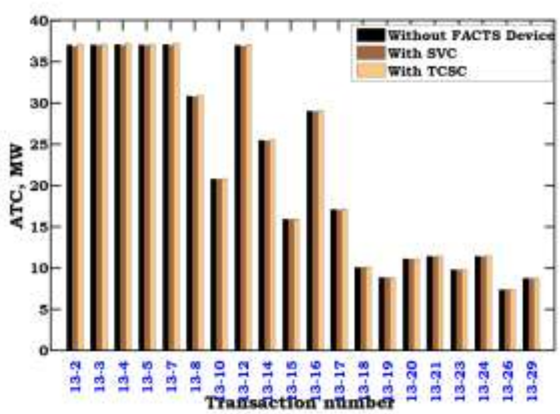

Fig.9. Variation of ATC values for possible bi-lateral transactions with generator at bus-13

V. CONCLUSION

In this paper, the power injection model of SVC and TCSC is presented to evaluate the possible ATC values with FACTS devices. The ACPTDF have been obtained for bi-lateral transactions with SVC and TCSC by using N-R load flow approach. In point of view of operational planning, the paper evaluated the impact of SVC and TCSC, which enables the balance of line flow and regulate node voltage simultaneously for evaluation of ATC. There is a considerable increase in ATC is observed in almost all the transactions with the usage of TCSC than compared to SVC. It is evident that, FACTS technology can offer an effective and promising solution to boost the usable power-transfer capability, thereby improving transmission services of the deregulated power system market.

REFERENCES

[1] Christie RD, Wollenberg BF, Wangstien I. Transmission management in the deregulated environment. Proc IEEE 2000;88(2):170–95.

[2] Ejebe GC, Tong J, Waight GG, Frame JG, Wang X, Tinney WF. Available transfer capability calculations. IEEE Trans Power Syst 1998;13(4):1521–7.

[3] Gravener MH, Nwankpa C. Available transfer capability and first order sensitivity. IEEE Trans Power Syst 1999;14(2):512–8.

[4] Ejebe GC, Waight JG, Santos-Nieto M, Tinney WF. Fast calculation of linear available transfer capability. IEEE Trans Power Syst 2000;15(3):1112–6.

[5] Greene S, Dobson I, Alvarado FL. Sensitivity of transfer capability margin with a fast formula. IEEE Trans Power Syst 2002;17(1).

[6] Grijalva S, Sauer PW, Weber JD. Enhancement of linear ATC calculations by the incorporation of reactive power flows. IEEE Trans Power Syst.2003;18(2):619–24.

[7] Kumar A, Srivastava SC, Singh SN. Available transfer capability (ATC) determination in competitive electricity market using AC distribution factors. Electric Power Components Syst. 2004;32: 927–39.

[8] Ghawghawe ND, Thakre KL. Computation of TCSC reactance and suggesting criterion of its location for ATC enhancement. Int J Electric Power Energy Syst. 2009;31:86–93.

[9] Kumar Ashwani, Kumar Jitendra. Comparison of UPFC and SEN transformer for ATC enhancement in restructured electricity markets. Int J Electric Power Energy Syst 2012;41:96–104.

[10] L. Gyugyi, A unified power flow control concept for flexible AC transmission systems, IEE Proc. Gener. Transm. Distrib. 139 (4) (1992) 323–331.

[11] N.G. Hingorani, Flexible AC transmission, IEEE Spectrum (1993) 40–45.

[12] F.D. Galiana, K. Almeida, M. Toussaint, J. Griffin, D. Atanackovic, B.T. Ooi, D.T.McGillis, Assessment and control of the impact of FACTS devices on power system performance, IEEE Trans. Power Syst. 11 (November) (1996) 1931–1936.

[13] C.A. Ca˜nizares, A. Berizzi, P. Marannino, Using FACTS controllers to maximize available transfer capability, in: Proceedings of Bulk Power Systems Dynamics and Control IV—Restructuring, Santorini, Greece, August, 1998, pp. 633–641.

[14] C.C. Liu, G.T.Heydt, A.A. Edris, Impact of FACTS controllers on transfer capability of power grids, in: Proceedings of IEEE PES Winter Meeting, January, 2002, pp.556–561.

[15] H. Farahmand, M. Rashidi-Nejad, M. Fotuhi-Firoozabad, Implementation of FACTS devices for ATC enhancement using RPF technique, in: Proceeding of Large Engineering Systems Conference on Power Engineering (LESCOPE), July,2004, pp. 30–35.

