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FAVORABLE TURF OF SVC & TCSC FOR ATC ENRICHMENT IN A DECONTROL ENVIRONMENT

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ABSTRACT

Improving of ATC is an important issue in the current de-regulated environment of power systems. The Available Transfer Capability (ATC) of a transmission network is the unutilized transfer capabilities of a transmission network for the transfer of power for further commercial activity, over and above already committed usage. Power transactions between a specific seller bus/area and a buyer bus/area can be committed only when sufficient ATC is available. Transmission system operators (TSOs) are encouraged to use the existing facilities more effectively to enhance the ATC margin. ATC can be limited usually by heavily loaded circuits and buses with relatively low voltages. It is well known that FACTS technology can control voltage magnitude, phase angle and circuit reactance. Using these devices may redistribute the load flow, regulating bus voltages. Therefore, it is worthwhile to investigate the impact of FACTS controllers on the ATC.

In this paper focuses on the evaluation of the impact of TCSC and SVC as FACTS devices on ATC and its enhancement during with and without line outage cases. In a competitive (deregulated) power market, optimal the location of these devices and their control can significantly affect the operation of the system and will be very important for ISO.

KEYWORDS: Available Transfer Capability (ATC), Continuous Power Flow (CPF), TCSC and SVC as FACTS.

I. INTRODUCTION

The aim of electric industry restructuring is to promote competitive markets for electric power trading. Under new environment, the main consequence of the nondiscriminatory open-access requirement is the substantial increase in power transfers. The Available Transfer Capability (ATC) of a transmission network is the unutilized transfer capabilities of a transmission network for the transfer of power for further commercial activity, over and above already committed usage. Adequate available transfer capacity (AATC) is needed to ensure all economic transactions, while sufficient ATC is needed to facilitate electricity market liquidity. It is necessary to maintain economical and secure operation over a wide range of system operating conditions and constraints. However, tight restrictions in the construction of new facilities due to the economic, environmental, and social problems, reduces the operational alternatives. It may sometimes lead to a situation that the existing transmission facilities are intensively used. On the other hand it can be said that power suppliers will benefit from more market opportunities with reduced possibility of congestion incorporating power systems security enhancement. Maximum use of existing transmission assets will be more profitable for transmission system owners; and customers will receive better services with reduced prices [8]. Various ATC boosting approaches have been experienced via adjusting generators' terminal voltages, under load tap changers (ULTCs) and rescheduling generator outputs. Based upon the NERC's definition of ATC and its determination [6], transmission network can be restricted by thermal, voltage and stability limits. On the other hand, it is highly recognized that, with the capability of flexible power flow [9], FACTS technology has introduced a severe impact to the transmission system utilization with regards to those three constraints. From the steady state power flow viewpoint, networks do not normally share power in proportion to their ratings, where in most situations, voltage profile cannot be smooth. Therefore, ATC values are always limited by heavily loaded buses with relatively low voltage. FACTS concept makes it possible to use circuit reactance, voltage magnitude, and phase angle as controls to redistribute line flow and regulate voltage profile.

Aim of the Thesis

The main aim of the Thesis is to enhance the Available Transfer Capability (ATC) from Generating/Source area to Sink area in a De-regulated environment system using Continuous Power Flow method during normal and contingency cases with optimal location and control parameter of FACTs Devices such as TCSC or SVC on IEEE 14-bus system and IEEE 24 reliability test system. Real-code Genetic Algorithm is used to determine location and control parameter of TCSC or SVC. ATC is dependent on many factors, such as the base case of system operation, system operation limits, network configuration, specification of contingencies etc,. FACTs technology has a sever impact to the transmission system utilization with regards to those constraints on ATC. Hence, maximum use of existing transmission assets will be more profitable for Transmission System Operators (TSO) and customers will receive better services with reduced prices

II. OVERVIEW OF AVAILABLE TRANSFER CAPABILITY

1. Introduction

In a deregulated power system structure, power producers and customers share a common transmission network for wheeling power from the point of generation to the point of consumption. All parties in this open access environment may try to produce the energy from the cheaper source for greater profit margin, which may lead to overloading and congestion of certain corridors of the transmission network. This may result in violation of line flow, voltage and stability limits and thereby undermine the system security. Utilities therefore need to determine adequately their “Available Transfer Capability (ATC)” to ensure that system reliability is maintained while serving a wide range of bilateral and multilateral transactions. The electric transmission utilities in the United States are required to post the information of ATC of their transmission network through the open access same time information system (OASIS) [6].

2. ATC Definitions

ATC is defined as the Total Transfer Capability (TTC) less the Transmission Reliability Margin (TRM), less the sum of existing transmission commitments (which includes retail customer service) and the Capacity Benefit Margin (CBM), shown in Fig.1 [6].

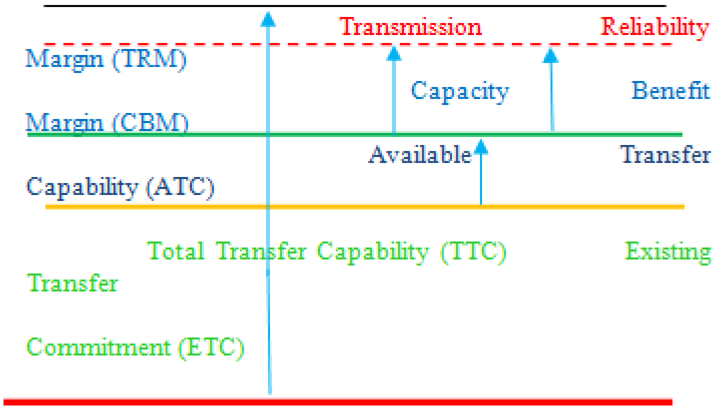

Fig.1 Basic Definition of ATC

Transmission Reliability Margin (TRM) is defined as that amount of transmission transfer capability necessary to ensure that the interconnected transmission network is secure under a reasonable range of uncertainties in system conditions.

Capacity Benefit Margin (CBM) is defined as that amount of transmission transfer capability reserved by load serving entities to ensure access to generation from interconnected systems to meet generation reliability requirements.

Mathematically, ATC is defined as [6]:

$$ATC= TTC-TRM-\{ETC+CBM\} \qquad (1)$$

3. Computational Methods

A 1996 report by North American Electric Reliability Council (NERC) establishes a framework for determining ATC of the interconnected transmission networks for a commercially viable wholesale market. The report defines ATC principles under which ATC values are to be computed and it permits individual systems, power pools, regions and sub regions to develop their procedure for determining ATC in accordance with these principles.

There are so many methods to compute ATC. In ref. [7], the topological information of a system is stored in a matrix form and constants for different simultaneous cases and critical contingencies have been calculated before hand and used for determination of ATC values. For very large systems, the method may be quite cumbersome. In ref. [7], the localized linearity of the system is assumed and additional loading required to hit the different transfer limits are separately calculated and the minimum of all these is taken as the ATC. The ATC is calculated by the following methods-

1. Method based on Continuation power flow.
2. Method based on distribution factors.

Method based on Continuation Power Flow

From the solved base case, power flow solutions are sought for increasing amounts of transfer in the specified direction [3]. The quantity of the transfer is a scalar parameter, which can be varied in the model. The amount of transfer is gradually increased from the base case until a binding limit is encountered. This continuation process requires a series of power system solutions to be solved and tested for limits. The transfer capability is the change in the amount of transfer from the base case transfer at the limiting point. Continuation can be simply done as a series of load flow calculations for increasing amounts of transfers. However, when convergence could be poor, such as the case for transfers approaching voltage instability, methods that allow the transfer parameter to become a dependent variable of the model are the most successful. Continuation Power Flow (CPF) is a method for finding the maximum value of a scalar parameter in a linear function of changes in injections at a set of buses in a power flow problem [7]. CPF yields solution even at voltage collapse points. A continuation power flow is performed by starting from an initial point and then increasing the load by a factor until some system limit is reached. The loads are defined as:

$$P_{Li} = \lambda P_{Loi}$$
$$Q_{Li} = \lambda Q_{Loi} \qquad (2)$$

Where P_{LOi}, Q_{LOi}, are the active and reactive power respectively of bus i in the base case; P_{Li}, Q_{Li} are the active and reactive power of bus i increased by parameter λ. For a specific source/sink transfer case calculation of the ATC may be summarized as the maximum transfer power without causing a limit violation over the base case.

4. Algorithm for ATC Calculation Using CPF

(i) a) Read the system line data and bus data

System data: From bus, To bus, Line resistance, Line reactance, half line charging, Off nominal turns ratio, maximum line flows.

Bus data: Bus no, Bus type, P_{gen}, Q_{gen}, P_{Load}, Q_{Load}, P_{min}, P_{max}, V_{sp} shunt capacitance data.

b) Cal $P_{shed}(i)$, $Q_{shed}(i)$, for i=1 to n

Where $P_{shed}(i) = P_{gen}(i) - P_{Load}(i)$

$Q_{shed}(i) = Q_{gen}(i) - Q_{Load}(i)$

c) Form Y_{bus} using sparsity technique

(ii) a) iter=1 iteration count

b) Set $\left|\Delta P_{max}\right| = 0$ and $\left|\Delta Q_{max}\right| = 0$

c) Calculate $P_{cal}(i) = \sum_{q=1}^{n} |V_i||V_q||Y_{iq}|\cos(\delta_{iq} - \theta_{iq})$

$$Q_{cal}(i) = \sum_{q=1}^{n} |V_i||V_q||Y_{iq}| \sin(\delta_{iq} - \theta_{iq})$$

d) Calculate $P(i) = P_{shed}(i) - P_{cal}(i)$
$Q(i) = Q_{shed}(i) - Q_{cal}(i)$ for i=1 to n
Set $P_{slack}=0.0$, $Q_{slack}=0.0$

e) Calculate $|\Delta P_{\max}|$ and $|\Delta Q_{\max}|$ form [Δ p] and [Δ Q] vectors

f) Is $|\Delta P_{\max}| \leq \in$ and $|\Delta Q_{\max}| \leq \in$
If yes go to step (vii), problem converged case

(iii) Form Jacobian elements
a) Initialize A[i][j]=0 for i=1 to 2n+2
j=1 to 2n+2

b) Form diagonal elements for i=1 to n

$$H_{pp} = \frac{\partial P_p}{\partial \delta_p} = -Q_p - B_{pp}|V_p|^2$$

$$N_{pp} = \frac{\partial P_p \cdot |V_p|}{\partial V_p} = P_p + G_{pp}|V_p|^2$$

$$M_{pp} = \frac{\partial Q_p}{\partial \delta_p} = P_p - G_{pp}|V_p|^2$$

$$L_{pp} = \frac{\partial Q_p |V_p|}{\partial V_p} = Q_p - B_{pp}|V_p|^2$$

c) Formation of off diagonal elements

$$H_{pq} = \frac{\partial P_p}{\partial \delta_q} = |V_p||V_q|\left(G_{pq}\sin\delta_{pq} - B_{pq}\cos\delta_{pq}\right)$$

$$N_{pq} = \frac{\partial P_p |V_q|}{\partial V_q} = |V_p||V_q|\left(G_{pq}\cos\delta_{pq} + B_{pq}\sin\delta_{pq}\right)$$

$$M_{pq} = \frac{\partial Q_p}{\partial \delta_q} = -N_{pq}$$

$$L_{pq} = \frac{\partial Q_p |V_q|}{\partial V_q} = H_{pq}$$

d) Modification of Jacobian elements for slack bus and generator buses
For slack bus
$H_{pp} = 10^{20}$
$L_{pp} = 10^{20}$
For PV buses $L_{pp} = 10^{20}$

e) Form right hand side vector
B[i] = Δ P[i], B [i+n] = Δ Q[i] for i=1 to n
Jacobian correction mismatch vector

(iv) Use Gauss-elimination method for solving

$$[A][\Delta X] = [B]$$

Update the phase angle and voltage magnitudes for i=1 to n

$$\delta_i = \delta_i + \Delta X_i$$

$$V_i = V_i + \{\Delta X_{i+n}\} V_i$$

(v) One iteration over
Advance iteration count iter=iter+1
If (iter>itermax) go to step (ii) (b)
Else go to step (vi).

(vi) NR is not converged in "itermax" iterations

(vii) NR is converged in 'iter' iterations calculate
  a. Line flows
  b. Bus powers, Slack bus power.
  c. Print the converged voltages, line flows and powers.

(viii) Read the sending bus (seller bus) *m* and the receiving bus (buyer bus) *n*.

(ix) Assume some positive real power injection change Δtp (=0.1) i.e. λ -factor at seller bus-*m* and negative injection Δtp (=0.1) i.e. λ -factor at the buyer bus-*n* and form mismatch vector.

(x) Repeat the load flow (i.e., from steps (ii) to (vii)) and from the new line flows check whether any of the line is overloaded. If yes stop the repeated power flow else go to (ix).

(xi) The maximum possible increment achieved above base-case load at the sink bus is the ATC.

III. MODELING of TCSC and SVC

1. Introduction

Power system is to be continuously expanded and upgraded to cater the ever-growing power demand. Due to limited energy resources, time and capital required, the present trend is looking for the new techniques for improving the power system performance. A new technology consisting of FACTS controllers has the ability to control the interrelated parameters that govern the operation of transmission system including series impedance, shunt admittance, current, voltage, phase angle and damping of oscillations at various frequencies below rated frequency. FACTs controller enables a line to carry power closer to its thermal rating. FACTs devices are the alternative transmission system incorporating power electronic based static controllers to enhance controllability and increase power transfer capability. Flexibility of AC transmission system refers to the ability to accommodate changes in the electric transmission system or operating conditions, while maintaining sufficient transient and steady state stability limit of the system [2].

Basic types of Facts Devices

In general, FACTS controllers can be divided into four categories:

(i) Series Controllers
(ii) Shunt Controllers
(iii) Combined Series-Series Controllers
(iv) Combined Series-Shunt Controllers

2. Simple two-machine power system model

Consider a two-machine model that is connected through a transmission line as shown in fig.2 [2].

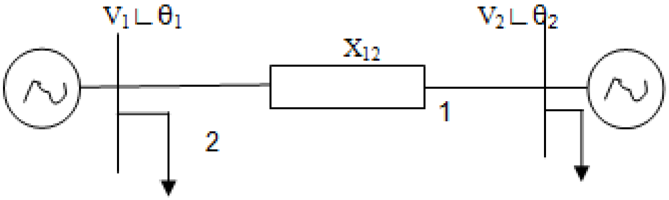

Fig. 2: Two-machine power system model

In an electrical network, value of the line conductance is close to zero and for most transmission lines; the line resistance is small compared to its reactance. By neglecting the line capacitance, the active and reactive powers transmitted by the line between two buses 1 and 2 may be approximated by the following equations [2]:

$$p_{12} = \frac{V_1 V_2}{X_{12}} \sin\theta_{12} \qquad (3)$$

$$Q_{12} = \frac{1}{X_{12}}(V_1^2 - V_1 V_2 \cos\theta_{12}) \qquad (4)$$

Where V_1 and V_2 are the voltages at buses 1 and 2, X_{12} is the line reactance and θ_{12} is the angle between V_1 and V_2. In high voltage transmission lines, $V_1 \approx V_2$ and θ_{12} is typically small. So there is a decoupling between controls of flows of the active versus reactive power. The active power flow is coupled with θ_{12} and the reactive power flow is linked to the difference (V_1-V_2). The control of X_{12} affects on both and modifies the active and reactive powers. Series Compensation permits to modify the reactance of the line X_{12} **[**12], and shunt compensation controls the voltage magnitudes of the load bus.

IV. CASE STUDIES AND DISCUSSION

The Available Transfer Capability (ATC) are computed for a set of source/sink transfers on IEEE 14-bus system and IEEE 24 reliability test system. The ATC margin can be further increased by proper location and control parameter of FACTs devices. In this thesis, TCSC and SVC are used as FACTs devices. Real-code Genetic Algorithm is used to find optimal location and control parameter of TCSC and SVC for maximizing of ATC. In this thesis, the total study is divided into two cases as:

1. ATC calculation without line outage.
2. ATC calculation with line outage.

The ATC margin is limited by bus voltage magnitude and line flow rating. The voltage magnitude limits of all buses are set to V_{min}=0.95 (p.u) and V_{max}=1.15 (p.u). The line ratings of IEEE 14-bus system and IEEE 24-bus system are given in appendix A and B respectively

1. IEEE 14-bus system

Without line outage case

Table-1: ATC without FACTS Device

Source/Sink bus no.	ATC (M.W)	Violation Constraint (line flow/voltage)
1/10	50.0	Line-8 overflow
1/9	43.0	Line-8 overflow
1/11	31.0	Line-8 overflow
1/14	29.5	Line-8 overflow
1/13	40.0	Line-8 overflow
1/12	219.0	Line-1 overflow
1/7	149.5	Line-2 overflow

The Available Transfer Capability (ATC) are computed for a set of source/sink transfers using Continuous Power Flow (CPF). Table-1 shows the ATCs for IEEE 14-bus system without FACTs device.

Incorporation of TCSC

When TCSC is incorporated in the system, if we consider all lines of system, there are 20 possible locations for the TCSC. The location code region are set as 20 integers as 1 to 20. The amount of compensation offered by TCSC is 0 to 40% (K_d). After using Real Genetic Algorithm proposed in this work, the results obtained are shown in Table-2. It shows that with the flow control function TCSC increased the ATC significantly.

Table-2: ATCs after incorporating TCSC

Sink bus no.	ATC without TCSC (M.W)	ATC with TCSC (M.W)	TCSC Location	Compensation (p.u)
1/9	51.0	65.5	Line-9	-0.078
1/10	42.0	61.0	Line-11	-0.081
1/12	29.0	50.0	Line -10	-0.120
1/13	30.5	43.5	Line -8	-0.111
1/14	39.0	51.5	Line -12	-0.123
1/4	212.0	248.0	Line -4	-0.069
1/3	152.5	211.5	Line -7	-0.077

Fig. 3 is the convergence characteristic of Real-code Genetic Algorithm and it shows a graph between generation and fitness function i.e., ATC (M.W) when source/sink transfer is between bus 1 and bus 9. After 89 generations, the optimal value of TCSC location and compensation value are found. It shows a good convergence of this algorithm.

The GA parameters selected were:

a) Population size = 40
b) Elitism probability = 0.15
c) Crossover probability = 0.60
d) Mutation probability = 0.01
e) Generations number = 100.

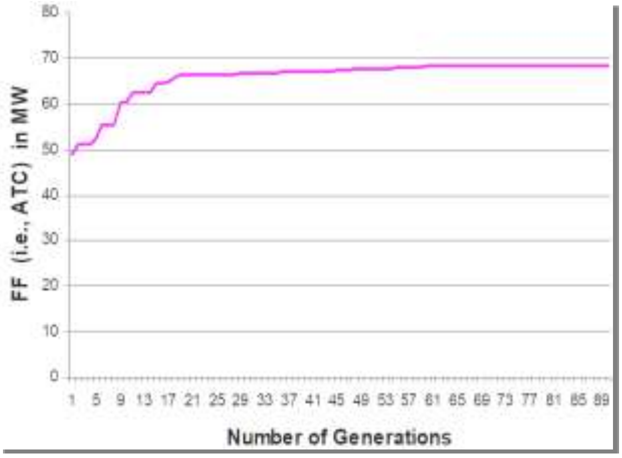

Fig. 3: No. of Generations Vs Fitness profile of ATC

Incorporation of SVC

When one SVC is incorporated in the system, if we consider all buses of system, there are 14 possible locations for the SVC. The location code region are set as 14 integers as 1 to 14. The amount of compensation offered by SVC is 0 to 0.1 (p.u) i.e., B_{svc}. After using Real Genetic Algorithm, the results obtained are shown in Table-5.3. It shows that with the flow control function SVC increased the ATC significantly. Fig. 4 shows the voltage profile for IEEE 14-bus system without and with SVC at bus-9, when ATC is computed for a transaction 1/9.

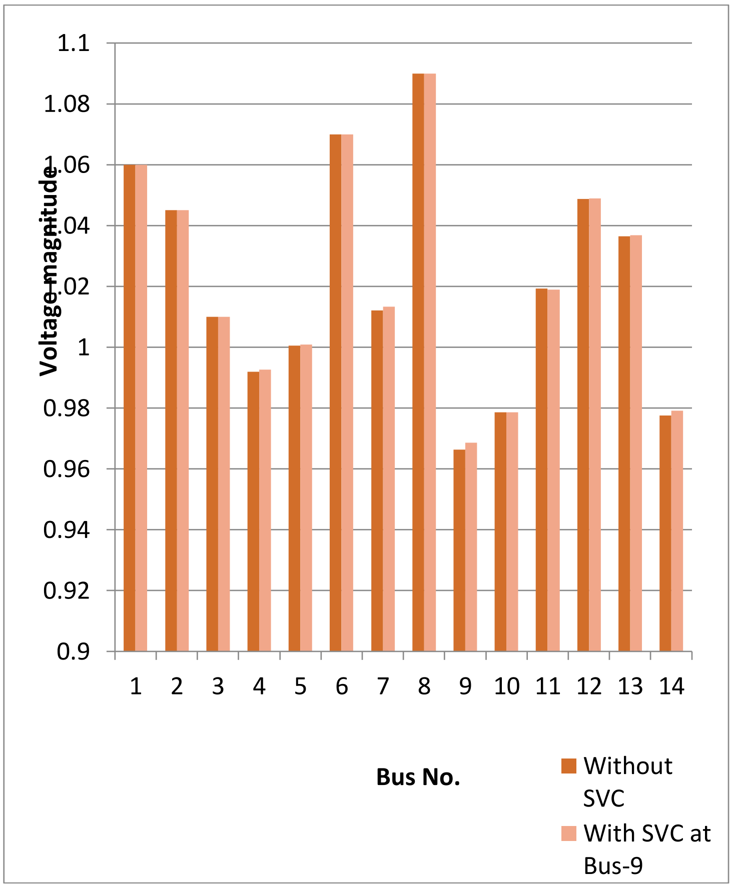

Fig. 4: voltage profile for IEEE 14-bus system without and with SVC at bus-9

Fig. 5: Bus voltage profile for without and with line outage cases

Incorporation of TCSC

When one TCSC is incorporated in the system, if we consider all lines of system, there are 19 possible locations for the TCSC. The location code region are set as 20 integers as 1 to 20 except line 16. The amount of compensation offered by TCSC is 0 to 40% (K_d). After using Real Genetic Algorithm proposed in this work, the results obtained are shown in Table-5.5. It shows that with the flow control function TCSC increased the ATC significantly even under line outage.

Incorporation of SVC

When one SVC is incorporated in the system, if we consider all buses of system, there are 14 possible locations for the SVC. The location code region are set as 14 integers as 1 to 14. The amount of compensation offered by SVC is 0 to 0.1 (p.u) i.e., B_{svc}. After using Real Genetic Algorithm, the results obtained are shown in Table-5.6. It shows that with the voltage control function SVC increased the ATC significantly during line-16 outage. Fig. 6 shows the voltage profile for IEEE 14-bus system without and with SVC at bus-13, when ATC is computed for a transaction 1/13.

Table-5.6: ATCs after incorporating SVC during line-16 outage

Sink bus no.	ATC without SVC (M.W)	ATC with SVC (M.W)	SVC Location	Compensation (p.u)
1/8	46.0	53.0	Bus-14	0.0664
1/11	43.0	43.0	Bus-10	0.0761
1/13	32.5	45.0	Bus-12	0.0840
1/12	25.5	38.5	Bus-13	0.0920
1/14	40.0	48.0	Bus-14	0.0881
1/5	220.0	255.5	Bus-9	0.768
1/6	149.5	158.5	Bus-10	0.0920

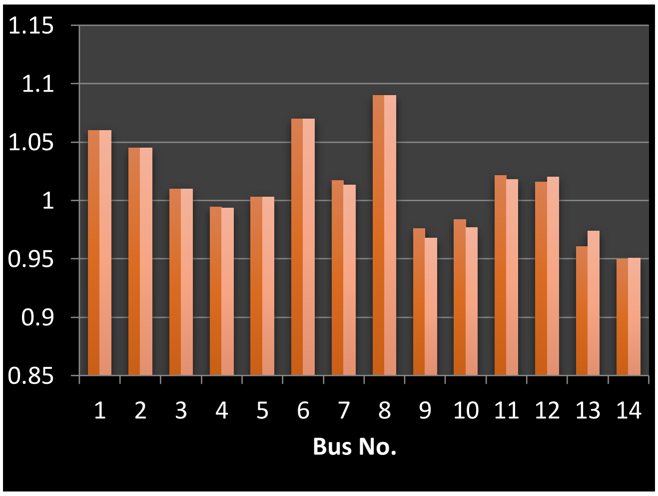

Fig. 6: Bus voltage profile for without and with SVC at bus-13

Table-3: ATCs after incorporating SVC

Source/Sink bus no.	ATC without SVC (M.W)	ATC with SVC (M.W)	SVC Location	Compensation (p.u)
1/9	51.0	59	Bus-9	0.081
1/10	43.0	47	Bus-10	0.079
1/12	28.0	38.5	Bus-12	0.092
1/13	29.5	40	Bus-13	0.089
1/14	41.5	52	Bus-14	0.090
¼	219.0	224	Bus-8	0.087
1/3	155.5	159.5	Bus-11	0.072

Table-4 line data 14 bus system

Bus	Type	P_{gen}	P_{load}	Q_{gen}	Q_{load}	$V_{specified}$	Y_{shunt}
1	Slack	0	0	0	0	1.05	0
2	P-V	0.4	0.217	0	0.127	1.035	0
3	P-V	0	0.872	0	0.145	1.002	0
4	P-Q	0	0.546	0	0.043	1.01	0
5	P-Q	0	0.045	0	0.043	1.2	0
6	P-V	0	0.342	0	0.045	1.05	0
7	P-Q	0	0	0	0	1	0.01
8	P-V	0	0.5	0	0.5	1.04	0
9	P-Q	0.4	0.25	0	0.134	1.01	0.19
10	P-Q	0	0.045	0	0.048	1	0
11	P-Q	0	0.045	0	0.055	1.03	0
12	P-Q	0	0.034	0	0.016	1	0
13	P-Q	0	0.152	0	0.046	1	0
14	P-Q	0	0.134	0	0.45	1.01	0

V. IEEE 14 BUS TEST SYSTEM

No. of buses: 14
No. of lines: 20
No. of generators: 5

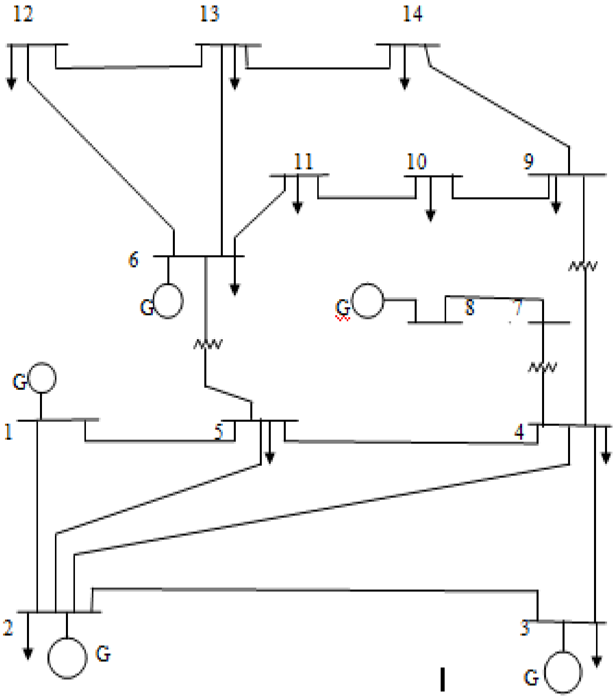

Fig.5: 14 bus system

VI. CONCLUSION

In deregulated power systems, available transfer capability (ATC) analysis is presently a critical issue either in the operating or planning because of increased area interchanges among utilities. Sufficient ATC should be guaranteed to support free market trading and maintain an economical and secure operation over a wide range of system conditions. However, tight restrictions on the construction of new facilities due to the increasingly difficult economic, environmental, and social problems, have led to a much more intensive shared use of the existing transmission facilities by utilities and independent power producers (IPPs). Based on operating limitations of the transmission system and control capabilities of FACTS technology, technical feasibility of applying FACTS devices to boost ATCs are analyzed and identified

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