# ATC Enhancement with Load Models -A Comprehensive Evaluation Using FACTS

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***Abstract— In order to facilitate the electricity market operation and trade in the restructured environment, ample trans-mission capability should be provided to satisfy the demand of increasing power transactions. The conflict of this requirement and the restrictions on the transmission expansion in the restructured electrical market has motivated the development of methodologies to enhance the Available Transfer Capability (ATC) of the existing transmission grids. The insertion of FACTS devices in electrical systems seems to be a promising strategy to enhance ATC. In this paper, the viability and technical merits of boosting ATC using Thyristor Controlled Series Compensator (TCSC) and Static Var Compensator (SVC) are being analyzed along with different load models like ZIP load model and Voltage Dependent Load model. The work has been carried out on IEEE 24 RTS bus system. Bilateral and multilateral transactions are considered. Cat Swarm Optimization (CSO) algorithm is employed to obtain the optimal settings of TCSC and SVC.***

***Keywords— Available Transfer Capability, Cat Swarm Optimization (CSO), Static Var Compensator (SVC), Thyristor Controlled Series Compensator (TCSC), Continuation power flow (CPF).***

## I. INTRODUCTION

Deregulation of the electric industry throughout the world aims at creating competitive markets to trade electricity, which generates a host of new technical challenges to market participants and power system re-searchers. For transmission networks, one of the major consequences of the non-Discriminatory open-access requirement is a substantial increase of power transfers, which demand adequate available transfer capability to ensure all economic transactions. Researchers have proposed various methods to evaluate ATC. 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). These concerns have motivated the development of strategies and methodologies to boost the ATC of the existing transmission networks.

Aimed at this problem, various ATC enhancement approaches have been proposed, where adjusting terminal voltage of generators and taps changing of on load tap changer (OLTC), particularly rescheduling generator outputs, are considered as major control measures for ATC boosting. On the other hand, it is highly recognized that, with the capability of flexible power-flow control and rapid action, flexible ac transmission systems (FACTS) technology has a wide spectrum of impacts on the way the transmission system operates, in particular with respect to thermal, voltage, and stability constraints.

ATC values are always limited ultimately by heavily loaded circuits and/or nodes with relatively low voltage, with the increase of system loading. FACTS concept makes it possible to use circuit reactance, voltage magnitude, and phase angle as controls to redistribute line flow and regulate nodal voltage, thereby mitigating the critical situation. In addition, partly due to the physical constraints on circuit impedance and phase angle of nodal voltage, most high-voltage transmission lines are operating far below their thermal rating. By the control of line reactance and voltage phase angle, FACTS technology enables line loading to increase flexibly, in some cases, all the way up to thermal limits. Therefore, theoretically it can offer an effective and promising alternative to conventional methods for ATC enhancement.

In this paper, ATC is made to enhance Available Transfer Capability using TCSC *i.e.* Thyristor controlled series compensator And SVC *i.e* Static Var Compensator. TCSC is connected in series with the line conductors to compensate for the inductive reactance of the line. SVC is connected in parallel with the line conductors to compensate for the inductive reactance of the line. Population based, cooperative and competitive stochastic search algorithm are very popular in the recent years in the research arena of computational intelligence. Some well-established search algorithm such as CSO is successfully implemented to solve simple and complex problems efficiently and effectively. The optimal set-tings of TCSC and SVC are obtained using CSO. The results are illustrated on IEEE 24 bus systems.

## II. AVAILABLE TRANSFER CAPABILITY (ATC)

### *A.* PROBLEM FORMULATION

ATC is a measure of the transfer capability remaining in the physical transmission network for further commercial activity over and above already committed uses. In other worlds it is the measure of residual transfer capability in the physical transmission network for the purpose of further commercial activity over existing transmission commitments. Mathematically, *ATC* is defined as the Total Transfer Capability less the Transmission Reliability Margin, less the sum of existing transmission commitments (which includes retail customer service) and the Capacity Benefit Margin.

ATC = TTC – TRM – Existing Transmission Commitments (including CBM).

Total Transfer Capability:

TTC is defined as the amount of electric power that can be transferred over the interconnected transmission network in a reliable manner while meeting all of a specific set of defined pre- and post-contingency system conditions.

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.

*B.* Cat Swarm Optimization (CSO) Technique

In the field of optimization, many algorithms were being proposed recent years, e.g. Genetic Algorithm (GA), Ant Colony Optimization (ACO), Particle Swarm Optimization (PSO), and Simulated Annealing (SA) etc. Some of these optimization algorithms were developed based on swarm intelligence. Cat Swarm Optimization (CSO), the algorithm, is motivated from PSO and ACO. According to the literatures, PSO with weighting factor usually finds the better solution faster than the pure PSO, but according to the experimental results, Cat Swarm Optimization (CSO) presents even much better performance.

In Cat Swarm Optimization, we first model the major two behaviors of cats into two sub-models, namely, seeking mode and tracking mode.

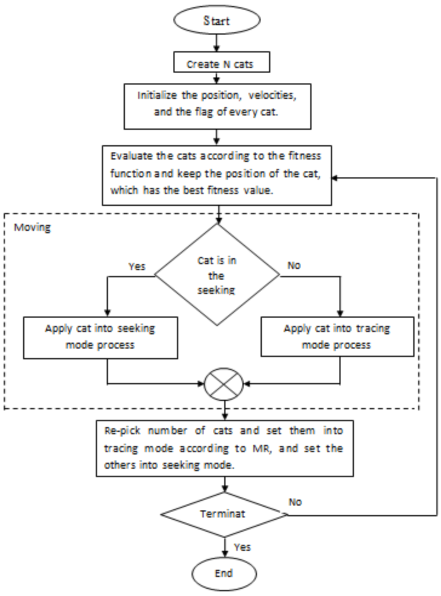
Seeking Mode:

This sub-model is used to model the situation of the cat, which is resting, looking around and seeking the next position to move to. In seeking mode, we define four essential factors: seeking range of the selected dimension (SRD), counts of dimension to change (CDC), and self-position considering (SPC).

Tracing Mode

Tracing mode is the sub-model for modeling the case of the cat in tracing some targets. Once a cat goes into tracing mode, it moves according to its' own velocities for every dimension.

C. Flow chart for the CSO technique




## III. Flexible AC Transmission System (FACTS) Devices

A. Static Var Compensator (SVC): A static VAR compensator (var is defined as volt ampere reactive) is a set of electrical devices for providing fast-acting reactive power on high-voltage electricity transmission networks. SVCs are part of the Flexible AC transmission system device family, regulating voltage, power factor, harmonics and stabilising the system. Unlike a synchronous condenser which is a rotating electrical machine, a static VAR compensator has no

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significant moving parts (other than internal switchgear). Prior to the invention of the SVC, power factor compensation was the preserve of large rotating machines such as synchronous condensers or switched capacitor banks. The SVC is an automated impedance matching device, designed to bring the system closer to unity power factor. SVCs are used in two main situations:

- Connected to the power system, to regulate the transmission voltage ("Transmission SVC")
- Connected near large industrial loads, to improve power quality ("Industrial SVC")

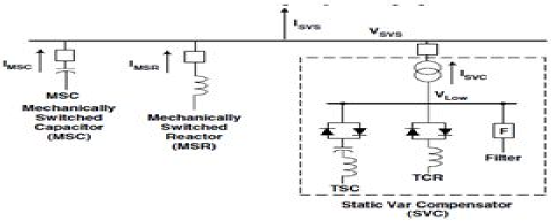


Fig 1: circuit for a Static Var Compensator (SVC)

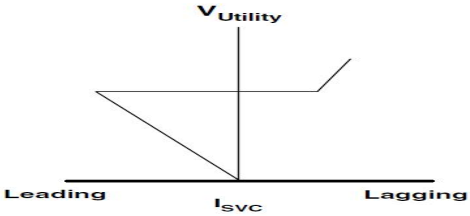


Fig 2: V-I characteristics of a SVC

B. Thyristor Controlled Series Compensator

A TCSC is a series-controlled capacitive reactance that can provide continuous control of power on the AC line over a wide range. It can be operated in both capacitive and inductive modes. In capacitive mode, it reduces the transfer reactance between the buses at which the line is connected, thus increasing the maximum power that can be transmitted and reducing the effective active and reactive power losses. From the system viewpoint, the principle of variable-series compensation is simply to in-crease the fundamental-frequency voltage across a fixed capacitor (FC) in a series-compensated line through ap-propriate variation of the firing angle, α. This enhanced voltage changes the effective value of the series- capacitive reactance.

The basic conceptual TCSC module comprises a series capacitor, C, in parallel with a thyristor controlled reactor, Ls as shown in **Figure 3**. However, a practical TCSC module also includes protective equipment normally installed with series capacitors.

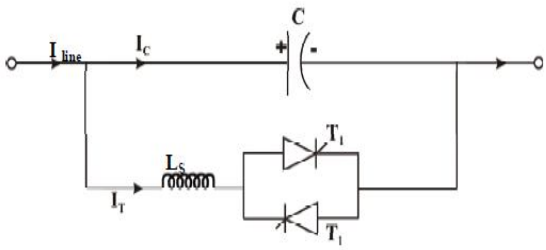


Fig 3: TCSC basic module

## IV. LOAD MODELS

### *A.* ZIP LOAD

Introduction

The static characteristics of the load can be classified into constant power, constant current and constant impedance load, depending on the power relation to the voltage. For a constant impedance load, the power dependence on voltage is quadratic, for a constant current it is linear, and for a constant power, the power is independent of changes in voltage**.**

Constant impedance:

In this model, active and reactive power injections at a given load bus vary directly with the square of nodal voltage magnitude. This model is also called constant admittance model.

$$P=f\,(v^2)$$

Examples for constant impedance loads are residential loads such as refrigerators and washing machines and lighting loads such as bulbs etc.

Constant current:

 

In this model, the active and reactive power injections at a given load bus vary directly with the nodal voltage magnitude**.**

$$P=f(v)$$

Examples for constant current load are transistors, transducers and incandescent lamps etc.

Constant power:

Here, the power of load bus is assumed to be constant and does not vary with nodal voltage magnitude**.**

$$P=k$$

Its active and reactive power models are given below:

$$P = P_0[a(U/U_0)2 + b_p(U/U_0) + c_p]$$
$$Q = Q_0[a_q(U/U_0)2 + b_q(U/U_0) + c_q]$$

Where $Q_0$, $P_0$ are power consumed by load at referent voltage, then we can get the following equations:

$$\mathbf{a_p + b_p + c_p = a_q + b_q + c_q = 1}$$

Through changing the coefficients, we may realize a host of ZIP loads. Examples for constant power loads are switching regulators, industrial loads such as motor loads with constant speed etc.

*B.* Voltage dependent load

A voltage dependent load is an electrical device whose power consumption varies with the voltage being supplied to it. Examples for voltage dependent loads are the most common types of incandescent lamps are standard tungsten filament, tungsten halogen and reflector lamps and motor loads.

## V. Results

*A.* 24 Bus System Using Both SVC & TCSC

There are three different cases as

Case 1: Base case

Case 2: (10-6) line outage

Case 3: Bus data change

SVC is connected at minimum voltage and TCSC is connected at minimum power flow. Now susceptance of SVC is varied from 0.1pu to 0.9pu and ATC value is observed. At 0.3pu susceptance the ATC is maximum. When compared to ATC value without FACTS. For TCSC the % of series compensation is varied from 20% to 80% and ATC value is observed. At 65% the ATC is maximum. When compared to ATC value without FACTS. When both SVC & TCSC are considered ATC is enhanced. After applying CSO the ATC value is enhanced more when compared with SVC & TCSC value.

Table 1: Summary of ATC for both SVC & TCSC Case1

| | Without FACTs | Only SVC | Only TCSC | Both SVC & TCSC |
|---|---|---|---|---|
| ATC (MW) | 7896.7 | 8044.1 | 8244.1 | 8402.6 |
| ATC After CSO | | 8184.1 | 8333.5 | 8535.2 |

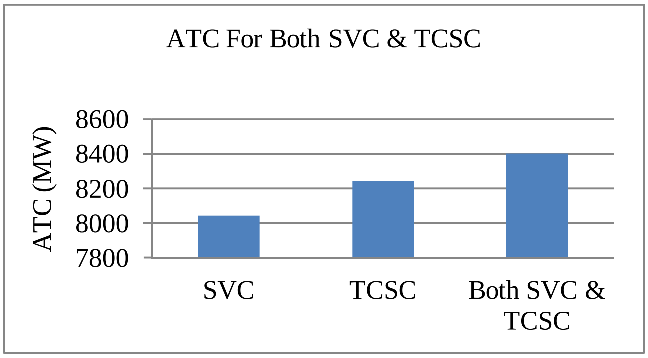


Fig: 1: ATC for both SVC & TCSC Case1

SVC is connected at minimum voltage and TCSC is connected at minimum power flow. Now susceptance of SVC is varied from 0.1pu to 0.9pu and ATC value is observed. At 0.9pu susceptance the ATC is maximum. When compared to ATC value without FACTS. For TCSC the % of series compensation is varied from 20% to 80% and ATC value is observed. At 20% the ATC is maximum. When compared to ATC value without FACTS. When both SVC & TCSC are considered ATC is enhanced. After applying CSO the ATC value is enhanced more when compared with SVC & TCSC value. The corresponding ATC values are tabulated.

 

Table 2: Summary of ATC for both SVC & TCSC Case2

| | Without FACTs | Only SVC | Only TCSC | Both SVC & TCSC |
|---|---|---|---|---|
| ATC (MW) | 6356.5 | 7224.5 | 7607.7 | 7857.0 |
| ATC After CSO | | 7268.9 | 7863.0 | 7996.9 |

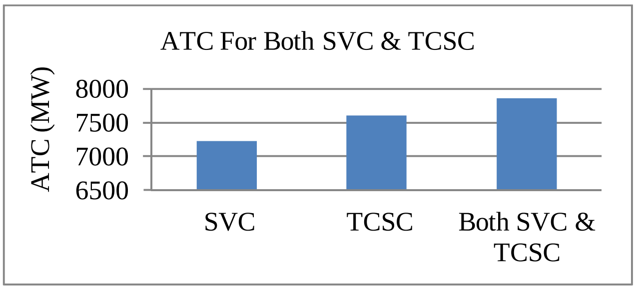


Fig 2: ATC for both SVC & TCSC Case2

SVC is connected at minimum voltage and TCSC is connected at minimum power flow. Now susceptance of SVC is varied from 0.1pu to 0.9pu and ATC value is observed. At 0.7pu susceptance the ATC is maximum. When compared to ATC value without FACTS. For TCSC the % of series compensation is varied from 20% to 80% and ATC value is observed. At 80% the ATC is maximum. When compared to ATC value without FACTS. When both SVC & TCSC are considered ATC is enhanced. After applying CSO the ATC value is enhanced more when compared with SVC & TCSC value. The corresponding ATC values are tabulated.

Table 3: Summary of ATC for both SVC & TCSC Case3

| | Without FACTs | Only SVC | Only TCSC | Both SVC & TCSC |
|---|---|---|---|---|
| ATC (MW) | 7701.6 | 8292.3 | 8417.7 | 8596.7 |
| ATC After CSO | | 8360.0 | 8558.7 | 8642.4 |

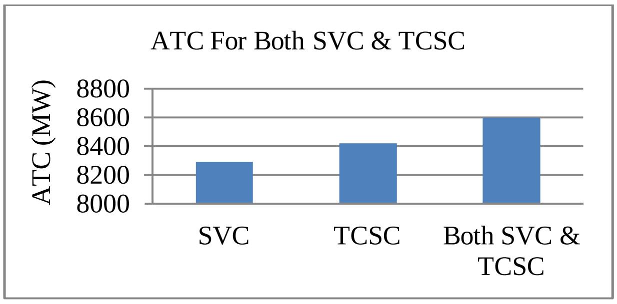


Fig 3: ATC for both SVC & TCSC Case3

*B.* ZIP Load With Both SVC & TCSC

SVC is connected at minimum voltage and TCSC is connected at minimum power flow. Now susceptance of SVC is varied from 0.1pu to 0.9pu and ATC value is observed. At 0.2pu susceptance the ATC is maximum. When compared to ATC value without FACTS. For TCSC the % of series compensation is varied from 20% to 80% and ATC value is observed. At 25% the ATC is maximum. When compared to ATC value without FACTS. When both SVC & TCSC are considered ATC is enhanced. After applying CSO the ATC value is enhanced more when compared with SVC & TCSC value. The corresponding ATC values are tabulated.

 

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Table 4: Summary of ATC for ZIP load both SVC & TCSC Case1

| | ZIP Load Without FACTs | ZIP load With SVC | ZIP load With TCSC | ZIP load Both SVC & TCSC |
|---|---|---|---|---|
| ATC (MW) | 8354.6 | 8442.5 | 8496.5 | 8900.1 |
| ATC After CSO | | 8467.5 | 8581.8 | 8990.9 |

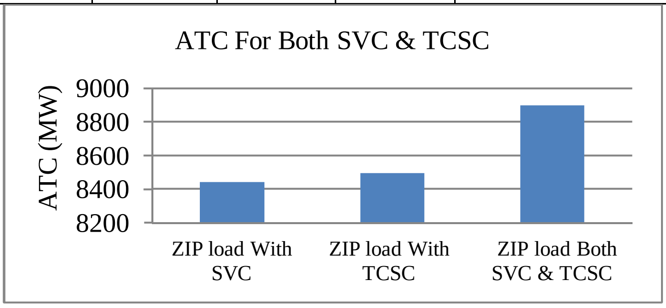


Fig: 4: ATC for ZIP load Both SVC & TCSC

SVC is connected at minimum voltage and TCSC is connected at minimum power flow. Now susceptance of SVC is varied from 0.1pu to 0.9pu and ATC value is observed. At 0.7pu susceptance the ATC is maximum. When compared to ATC value without FACTS. For TCSC the % of series compensation is varied from 20% to 80% and ATC value is observed. At 35% the ATC is maximum. When compared to ATC value without FACTS. When both SVC & TCSC are considered ATC is enhanced. After applying CSO the ATC value is enhanced more when compared with SVC & TCSC value. The corresponding ATC values are tabulated.

Table 5: Summary of ATC for ZIP load both SVC & TCSC Case2

| | ZIP Load Without FACTs | ZIP load With SVC | ZIP load With TCSC | ZIP load Both SVC & TCSC |
|---|---|---|---|---|
| ATC (MW) | 7712.0 | 7906.5 | 8115.5 | 8800.7 |
| ATC After CSO | | 8052.8 | 8198.0 | 8889.3 |

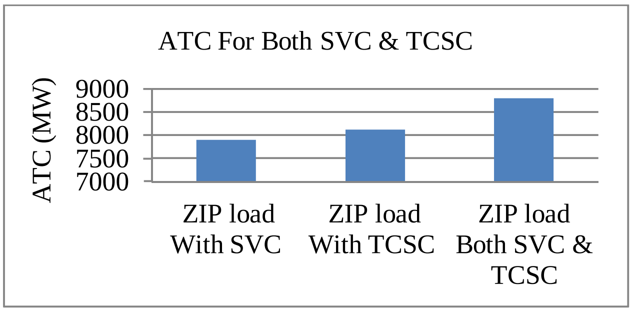


Fig 5: ATC for ZIP load Both SVC & TCSC

SVC is connected at minimum voltage and TCSC is connected at minimum power flow. Now susceptance of SVC is varied from 0.1pu to 0.9pu and ATC value is observed. At 0.7pu susceptance the ATC is maximum. When compared to ATC value without FACTS. For TCSC the % of series compensation is varied from 20% to 80% and ATC value is observed. At 35% the ATC is maximum. When compared to ATC value without FACTS. When both SVC & TCSC are considered ATC is enhanced. After applying CSO the ATC value is enhanced more when compared with SVC & TCSC value. The corresponding ATC values are tabulated.

 

Table 6: Summary of ATC for ZIP load both SVC & TCSC Case3

| | ZIP Load Without FACTs | ZIP load With SVC | ZIP load With TCSC | ZIP load Both SVC & TCSC |
|---|---|---|---|---|
| ATC (MW) | 8245.1 | 8363.6 | 8450.5 | 8700.4 |
| ATC After CSO | | 8417.7 | 8546.6 | 8755.4 |

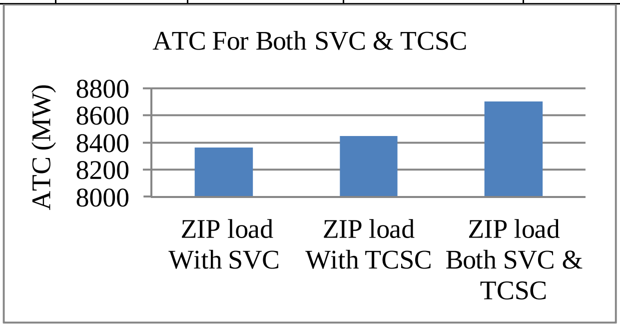


Fig: 6 ATC for ZIP load Both SVC & TCSC

### C. Voltage Dependent Load With Both SVC & TCSC

SVC is connected at minimum voltage and TCSC is connected at minimum power flow. Now susceptance of SVC is varied from 0.1pu to 0.9pu and ATC value is observed. At 0.6pu susceptance the ATC is maximum. When compared to ATC value without FACTS. For TCSC the % of series compensation is varied from 20% to 80% and ATC value is observed. At 30% the ATC is maximum. When compared to ATC value without FACTS. When both SVC & TCSC are considered ATC is enhanced. After applying CSO the ATC value is enhanced more when compared with SVC & TCSC value. The corresponding ATC values are tabulated.

Table 7: Summary of ATC for VOLT DEP load both SVC & TCSC Case1

| | VOLT DEP LOAD Without FACTs | VOLT DEP load With SVC | VOLT DEP load with TCSC | VOLT DEP load Both SVC & TCSC |
|---|---|---|---|---|
| ATC (MW) | 8146.8 | 8199.3 | 8230.1 | 8481.5 |
| ATC After CSO | | 8259.0 | 8363.6 | 8599.8 |

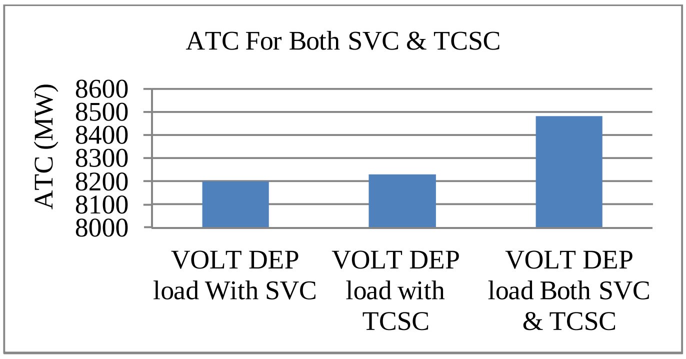


Fig: 7: ATC for Voltage Dependent Load Both SVC & TCSC

SVC is connected at minimum voltage and TCSC is connected at minimum power flow. Now susceptance of SVC is varied from 0.1pu to 0.9pu and ATC value is observed. At 0.2pu susceptance the ATC is maximum. When compared to ATC value without FACTS. For TCSC the % of series compensation is varied from 20% to 80% and ATC value is observed. At 50% the ATC is maximum. When compared to ATC value without FACTS. When both SVC & TCSC are considered ATC is enhanced. After applying CSO the ATC value is enhanced more when compared with SVC & TCSC value. The corresponding ATC values are tabulated.

Table 8: Summary of ATC for Voltage Dependent load both SVC & TCSC Case2

| | VOLT DEP LOAD Without FACTs | VOLT DEP load With SVC | VOLT DEP load with TCSC | VOLT DEP load Both SVC & TCSC |
|---|---|---|---|---|
| ATC (MW) | 6356.5 | 7805.1 | 7883.1 | 8372.6 |
| ATC After CSO | | 7997.2 | 7963.8 | 8464.6 |

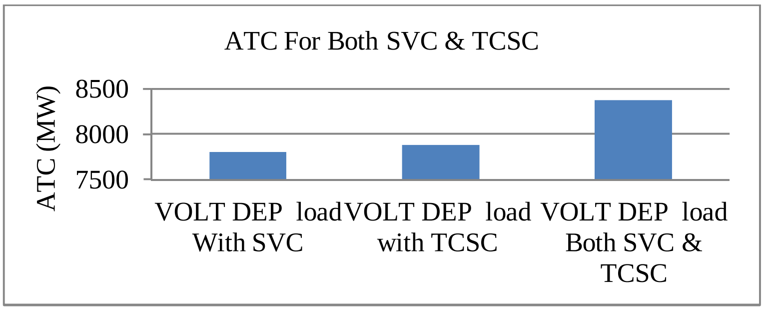


Fig 8: ATC for Voltage Dependent Load Both SVC & TCSC

SVC is connected at minimum voltage and TCSC is connected at minimum power flow. Now susceptance of SVC is varied from 0.1pu to 0.9pu and ATC value is observed. At 0.9pu susceptance the ATC is maximum. When compared to ATC value without FACTS. For TCSC the % of series compensation is varied from 20% to 80% and ATC value is observed. At 80% the ATC is maximum. When compared to ATC value without FACTS. When both SVC & TCSC are considered ATC is enhanced. After applying CSO the ATC value is enhanced more when compared with SVC & TCSC value. The corresponding ATC values are tabulated.

Table 9: Summary of ATC for Voltage Dependent load both SVC & TCSC Case3

| | VOLT DEP LOAD Without FACTs | VOLT DEP load With SVC | VOLT DEP load with TCSC | VOLT DEP load Both SVC & TCSC |
|---|---|---|---|---|
| ATC (MW) | 7596.7 | 8109.1 | 8235.4 | 8559.1 |
| ATC After CSO | | 8330.5 | 8402.3 | 8660.7 |

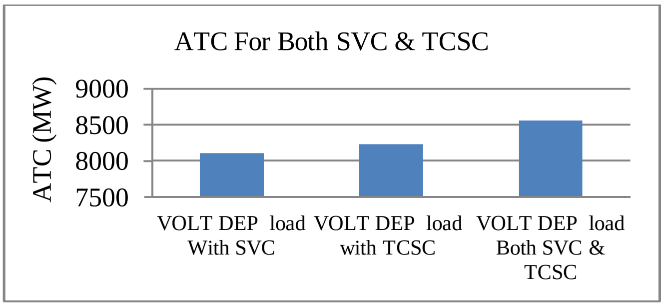


Fig 9: ATC for Voltage Dependent Load Both SVC & TCSC

## VI. Conclusions

From the view point of operational planning, this paper evaluated the impact of FACTS device on ATC enhancement. The results demonstrated that the use of FACTS devices, particularly the TCSC and SVC can boost the ATC substantially. The considerable difference between ATC values with and without TCSC and SVC justifies that the FACTS technology can offer an effective and promising solution to boost the usable power transfer capability, thereby improving transmission services of the competitive electricity market. On using CSO for the above problem, it is found that, CSO algorithm is providing very good enhanced result with minimum execution time. CSO algorithm predicted the same limiting line for transactions considered in IEEE 24 bus test systems.

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