

## **SVC Placement for ATC Enhancement using WIPSO Technique**

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### **Abstract**

Available transfer Capacity (ATC) is an important issue for accommodating further transaction over and above already existing commitments. Determination and enhancement of ATC are important factor in deregulated operation of power systems. ATC enhancement with optimal FACTS devices can plays an important role in an efficient and secure operation of competitive markets. This paper presents a PSO algorithm based optimization technique is used for optimal placement of SVC'S for enhancing the transfer capacity of the transmission lines. The problem is solved by taking into account the variations in wheeling transactions across any two selected buses and the algorithm is used for enhancing the ATC under various load conditions in an emission economic dispatch environment and the results are compared against those obtained using WIPSO technique. The effectiveness of the proposed algorithm is demonstrated on IEEE 14, 30 and 57 bus test systems.

**Keywords:** FACTS Devices, Static Var Compensator (SVC), Particle swarm Optimization (PSO), Weight Improved Particle Swarm Optimization (WIPSO), Available Transfer Capacity (ATC).

### **Introduction**

Deregulation of electric power industry aims at creating competitive markets to trade electricity and it generates a host of technical problems that need to be addressed. One of the major requirements of open access environment is the presence of adequate of Available Transfer Capacity in order to maintain economy and ensure secure operation over a wide range of operating conditions. There are several approaches to

enhance the ATC, some of the commonly adopted techniques are to adjust the settings of OLTCs and rescheduling generator outputs.

With the capability of flexible power flow control and rapid action, Flexible AC Transmission systems technology has a greater impact over the thermal, voltage and stability constraints of the system. With the increase in system loading ATC values are ultimately limited by the heavily loaded circuits or nodes with relatively low voltages. FACTS concept uses circuit reactance, voltage magnitude and phase angles as control variables to redistribute line flow and regulate nodal voltages improve thereby mitigations the critical situation.

The impact of FACTS devices on ATC enhancement is evaluated by using cat swarm Optimization has been demonstrated in (1). ATC determination based on AC power transfer distribution factors for multi –transaction cases with intact case and the optimal placement of SVC device based on sensitivity indices has been proposed in (2). The AC power transmission congestion distribution factor (PTCDF) can be used to calculate the ATC and ATC calculations can be used to solve congestion problem in restructured electrical power network is proposed in (3). ATC determination for bilateral and multilateral transactions based on PTDF's and FACTS devices placement through power flow sensitivity analysis is reported in (4). Genetic algorithm can be used to find optimal location and setting of the combined TCSC and SVC for maximizing ATC and minimizing contingency of power systems in (5). Hybrid mutation PSO for enhancing ATC has been proposed in (6). A sensitivity based approach has been developed for finding the optimal placement of FACTS devices in a deregulated market and it is shown in the results installing SVC as FACTS devices improve voltage profile as well as enhancing ATC. (7) The improvement of ATC using TCSC and SVC during normal as well as contingency situations is studied in (8). Weight improved PSO algorithm has been applied to the combined Economic and Emission Dispatch CEED problem is suggested in(9). A multi objective chaotic ant swarm optimization (MOCASO) method for solving economic and emission dispatch (EED) problems of thermal generators in power systems is presented in (10). A comparison analysis has been done for different intelligent techniques such as genetic algorithm (GA), evolutionary techniques (EP), particle swarm optimisation (PSO) and differential evolution (DE) applied for solving combined economic emission dispatch problems is proposed in (11). The optimal power flow (OPF) based total transfer capability (TTC) calculation with transmission Reliability margin (TRM) using Differential Evaluation (DE) is presented in (12). Multi area ATC determination using ACPTDF's and PF's in a CEED environment has been discussed in (13). Real genetic algorithm (RGA) associated with analytical hierarchy process (AHP) and fuzzy sets can be implemented to determine the best location and optimal capacity of TCSC in order to increase ATC is proposed in (14) and this new proposed methodology is implemented using repeated power flow procedure. The ATC is computed for various transactions using continuous power flow method. The Real coded genetic algorithm has been proposed to determine the location and compensation level of TCSC or SVC with maximizing the Available transfer capability (ATC) in (15). A new model for combined optimal location of TCPAR and TCSC has been proposed for a pool and hybrid market model to enhance the system loadability in (16). AC distribution factor

has been defined for ATC determination under system intact and line outage conditions is proposed in (17). An optimal power flow based FACTS device placement with an objective of maximizing the power flow across a specified interface is discussed in (18). The transient stability and power flow models for SVC and TCSC are presented in (19). A sensitivity based approach is developed for finding suitable placement of TCSC device for enhancement of total transfer capability has been approached in (20).

As FACTS devices enable the line loadings to increase even up to their thermal limits they offer a more promising alternative to conventional methods of ATC enhancement.

Here, it is proposed to calculate ATC using ACPTDF (AC Power Transfer Distribution Factor) in a combined Economic emission dispatch environment and an attempt is going to be made to place the SVC'S and fix their ratings so as to increase the ATC values. The optimal settings and location of SVC'S are obtained from WIPSO algorithm.

### Available Transfer Capability

Available Transfer Capability ATC is a measure of the transfer capability remaining in the physical transmission network for further commercial activity over and above the already committed uses.

$$ATC = TTC - \text{Existing Transmission Commitments}$$

Where TTC is Total Transfer Capability is defined as the amount of electric power that can be transmitted over the interconnected transmission network in a reliable manner while meeting all of a specific set of pre and post contingency conditions.

ATC at base case between bus m and n using line flow limit criterion is mathematically formulated using

$$ATC_{mn} = \min \{T_{ij,mn}\}, ij \in NL \tag{1}$$

Where,

$T_{ij,mn}$  is the transfer limit values for each line in the system.

$$T_{ij,mn} = \left\{ \begin{array}{ll} \frac{(P_{ij}^{max} - P_{ij}^0)}{PTDF_{ij,mn}} ; & \text{if } PTDF_{ij,mn} > 0 \\ \infty (infinite) ; & \text{if } PTDF_{ij,mn} = 0 \\ \frac{(-P_{ij}^{max} - P_{ij}^0)}{PTDF_{ij,mn}} ; & \text{if } PTDF_{ij,mn} < 0 \end{array} \right\} \tag{2}$$

Where

$P_{ij}^{max}$  is MW power limit of a line l between buses i and j

$P_{ij}^0$  is the base case power flow in line l between buses i and j

$PTDF_{ij,mn}$  is the power transfer distribution factor for the line  $l$  between bus  $i$  and  $j$  when there is a transaction between buses  $m$  and  $n$

NL = number of lines

$P_{ij}^{max}$  is MW power limit of a line  $l$  between buses  $i$  and  $j$

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NL = number of lines

### CEED Problem Formulation:

The Combined Emission Economic Dispatch problem is formulated using the following equation.

$$\phi = \min \sum_{i=1}^{Ng} f(FC, EC). \quad (3)$$

Where,

$\Phi$  is the optimal cost of generation in Rs/hr

FC and EC are the total fuel cost and emission cost of generators.

$Ng$  represents the total no. of generators connected in the network.

The cost is optimized following the standard equality and inequality constraints.

$$\sum_{i=1}^{Ng} p_{gi} = p_d + p_l$$

$$p_{gi}^{\min} \leq p_{gi} \leq p_{gi}^{\max}$$

Where,

$P_{gi}$  is the power output of the  $i^{\text{th}}$  generating unit.

$P_d$  is the Total load of the system

$P_l$  is the transmission losses of the system.

$p_{gi}^{\min}$  and  $p_{gi}^{\max}$  are the minimum and maximum values of real power allowed at generator  $i$  respectively.

The bi-objective CEED problem is converted into single optimization problem by introducing price penalty factor  $h$  and CEED optimization is solved using evolutionary programming.

### ACPTDF Formulation:

The AC power transfer distribution factor is explained below.

A bilateral transaction  $t_k$  between a seller bus  $m$  and buyer bus  $n$  is considered. Line  $l$  carries the part of the transacted power and is connected between bus  $i$  and  $j$ . For a change in real power transaction among the above buyer and seller by  $\Delta t_k$  MW, if the change in transmission line quality  $q_l$  is  $\Delta q_l$ , PTDF is defined as

$$PTDF_{ij,mn} = \frac{\Delta q_l}{\Delta t_k} \quad (4)$$

Where,

$\Delta t_k$  = change in real power transaction among the buyer and seller by  $\Delta t_k$

$\Delta q_l$  = change in transmission line quality  $\Delta q_l$ . The transmission quality  $q_l$  can be either real power flow from bus  $i$  to  $j$  ( $p_{ij}$ ) or real power flow from bus  $j$  to  $i$  ( $P_{ij}$ ). The Jacobian matrix for NR power flow is given by

$$\begin{pmatrix} \Delta\delta \\ \Delta V \end{pmatrix} = \begin{pmatrix} \frac{\partial P}{\partial\delta} & \frac{\partial P}{\partial V} \\ \frac{\partial Q}{\partial\delta} & \frac{\partial Q}{\partial V} \end{pmatrix}^{-1} \begin{pmatrix} \Delta P \\ \Delta Q \end{pmatrix} = [J]^{-1} \begin{pmatrix} \Delta P \\ \Delta Q \end{pmatrix} \quad (5)$$

If only one of the  $K^{th}$  bilateral transactions is changed by  $\Delta t_k$  MW, only the following two entries in mismatch vector on the RHS will be non-zero.

$$\begin{aligned} \Delta P_i &= \Delta t_k \\ \Delta P_j &= -\Delta t_k \end{aligned} \quad (6)$$

With the above mismatch vector element, the change in voltage angle and magnitude at all buses can be computed from (5) and (6) and hence the new voltage profile can be computed. These can be utilized to compute all the transmission quantities  $q_l$  and hence the corresponding changes in these quantities  $\Delta q_l$  from the base case.

Once  $\Delta q_l$  for all the lines corresponding to a change in  $\Delta t_k$  is known, PTDF'S can be obtained from the formula.

### Role of FACTS Devices

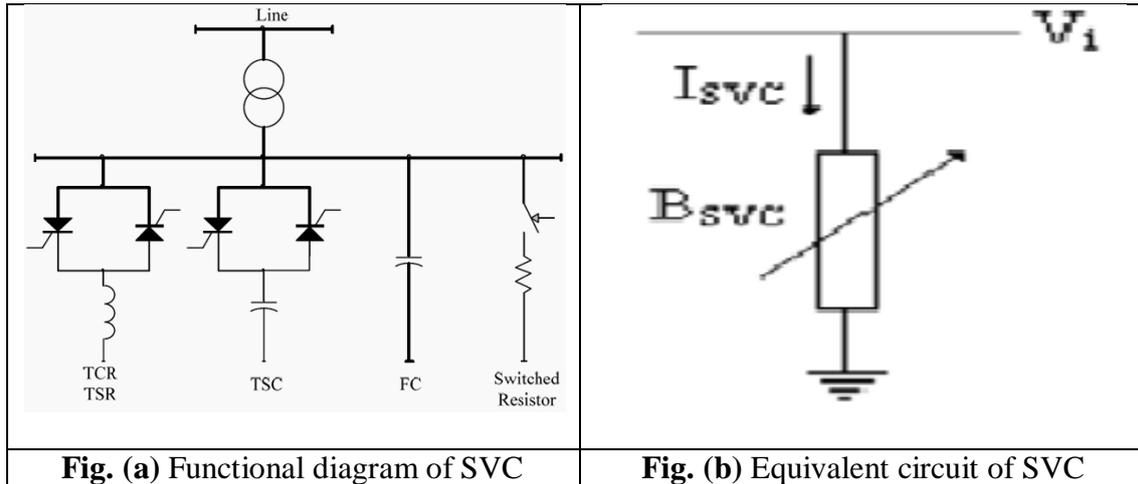
The role of Flexible AC Transmission systems (FACTS) in the open market is to manage the congestion, enhancing security, reliability, increasing power transfer capability, controlled flow of power and other system performances.

### Modelling of SVC:

The Static Var Compensator (SVC) is a shunt connected FACTS device whose main functionality is to regulate the voltage at a given bus by controlling its equivalent reactance. The SVC may have two characteristics namely, inductive and capacitive. When the system voltage is low, the SVC generates reactive power (SVC capacitive). when the system voltage is high, the SVC absorbs reactive power (SVC inductive). SVC includes two main components and their combination. Thyristor – controlled and Thyristor – switched Reactor (TCR and TSR) and Thyristor – switched capacitor (TSC) as shown in Fig. (a). It is modelled as an ideal reactive power injection at bus  $i$ , as shown in Fig. (b)

$B_{SVC}$  represent the controllable susceptance of SVC. it is used for voltage control applications. It helps to maintain a bus voltage at a desired value during load variation.

It has the advantages over series capacitors where compensation is required to prevent voltage sag at the bus involving multiple lines, total cost may be less than that for series compensation of each of the lines. The working range of SVC is between -100Mvar and +100MVar.



### Over View of PSO

PSO was first introduced by Kennedy and Eberhart in 1995. Heuristic optimization technique introduced by the swarm intelligences of animals such as bird flocking, fish schooling. A swarm of particles represents a solution to the optimization problem. Each particle adjusts its position according to its own experience and the experience of its neighbouring particles. The position and velocity of  $i^{th}$  particle in the N – dimensional search space is represented as

$$X_i = (x_{i1}, x_{i2}, \dots, x_{in})$$

$$v_i = (v_{i1}, v_{i2}, \dots, v_{in})$$

The best position achieved by a particle is recorded and is denoted by

$$P_{best\ i} = (x_{i1}^{P_{best}}, \dots, x_{in}^{P_{best}})$$

The best particle among all the particles in the population is represented by

$$G_{best\ i} = (x_{i1}^{G_{best}}, \dots, x_{in}^{G_{best}})$$

The updated velocity and position of each particle in  $(K + 1)^{th}$  step are calculated as follows

$$X_i^{k+1} = X_i^k + V_i^{k+1}$$

Where,

$$V_i^{k+1} = wV_i^k + C_1 rand_1 (x_i P_{best\ i}^k - x_i^k) + C_2 rand_2 (G_{best\ i}^k - x_i^k)$$

$x_i^k$  = Position of individual i at iteration k

$X_i^{k+1}$  = Position of individual i at iteration k + 1

$v_i^k$  = Velocity of individual i at iteration k

W = weight parameter

$C_1$  = Cognitive factor

$C_2$  = Social factor

$P_{best\ i}^k$  = best position of individual i until iteration k

$G_{best\ i}^k$  = best position of group until iteration k

$rand_1, rand_2$  = random numbers between 0 and 1.

In this velocity updating process, the acceleration coefficients  $C_1, C_2$  and weight parameter 'w' are predefined and  $rand_1$  and  $rand_2$  are uniformly generated random numbers in the range of [0, 1].

### Weight Improved Particle Swarm Optimization

To get a better global solution, the algorithm is improved by adjusting the weight parameter, cognitive and social factors. The velocity of the individual using WIPSO is rewritten as

$$V_i^{k+1} = W_{new} V_i^k + C_1 rand_1 (p_{best_i}^k - x_i^k) + C_2 rand_2 (G_{best_i}^k - x_i^k)$$

Where,

$$W = w_{max} - \left\{ \frac{w_{max} - w_{min}}{Iter_{max}} \right\} x Iter$$

$$W_{new} = (W_{min}) + (W \times rand_3)$$

$$C1 = C1_{max} - \left\{ \frac{C1_{max} - C1_{min}}{Iter_{max}} \right\} x Iter$$

$$C2 = C2_{max} - \left\{ \frac{C2_{max} - C2_{min}}{Iter_{max}} \right\} x Iter$$

$w_{min}, w_{max}$  = initial and final weights

$C1_{min}, C1_{max}$  = initial and final cognitive factors

$C2_{min}, C2_{max}$  = initial and final social factors

$Iter_{max}$

maximum iteration number

$Iter$  = current iteration number

$rand_3$  = random numbers between 0 and 1

### Algorithm:

1. Choose the population size, the number of generations,  $w_{min}, w_{max}, C1_{min}, C1_{max}, C2_{min}, C2_{max}, p_{best}, g_{best}$ . (Population size 10, no. of generations 200)
2. Initialize the velocity and position of all particles randomly, ensuring that they are within limits. Here the individuals represent the real power generation of generator buses in the system.
3. Set the generation counter  $t=1$ .
4. Evaluate the fitness for each particle according to the objective function.
5. Compare the particle's fitness function with its  $P_{best_i}$ . If the current value is better than  $P_{best_i}$ , then set  $P_{best_i}$  is equal to the current value. Identify the particle in the neighborhood with the best success so far and assign it to  $G_{best}$ .
6. Update velocity by using the global best and individual best of the particle.
7. Update position by using the updated velocities. Each particle will change its position.
8. If the stopping criteria is not satisfied set  $t=t+1$  and go to step 4. Otherwise stop.

## 6. PROBLEM FORMULATION

The objective is to maximize the ATC between the sending and receiving end buses.

$$ATC = \max \sum_{i=1}^{NL} P_i^{max} - P_i^{flow}$$

Where,

$P_i^{max}$  is the thermal limit of the line.

$P_i^{flow}$  is the base case flow of the line

In order to maximize ATC, suitable locations are to be identified and the placement of SVC and their ratings are to be fixed.

### Algorithm for ATC Enhancement:

1. Read the system input data.
2. Run the base case load flow in the combined emission economic dispatch setting of generators.
3. Consider the wheeling transaction  $t_k$  alone.
4. Compute AC power transfer distribution factor.
5. Taking in to account the line flow limits based upon Stability and thermal limits, determine the value of ATC.
6. Arrange ATC in ascending order.
7. Fix the number of SVC's that is to be connected in the system.
8. Run the PSO algorithm to obtain the location and rating of SVC's.
9. Calculate ATC after incorporating SVC's.
10. Consider the next wheeling transaction  $t_k$  and go to step 4.

## Simulation and Test Results

The proposed SVC placement algorithm using PSO and WIPSO techniques has been tested on standard IEEE 14, 30 and 57 bus test systems. A bilateral transaction has been initiated between buses 12 and 13 in a common emission economic dispatch environment and the ratings and locations of SVC's are fixed with an objective of improving the ATC for the above mentioned transaction. The ATC values are obtained through ACPTDF calculated for the particular transaction using the NR Jacobian. The number of SVC's has been limited as 3 taking into consideration the cost of the device. The test results for the ATC enhancement problems are given in Tables for 14, 30 and 57 bus systems.

To study the implementation of SVC for ATC enhancement, the load on the system were increased in a step by step manner. The improvement in ATC results of the system with and without SVC can be represented in the Tables 7. 1, 7. 2 and 7. 3 and an equivalent bar chart also represent for all the three systems for various load conditions are represented in Fig. 7. 1 to 7. 6. The results have also been obtained by WIPSO technique for comparisons.

**Table 7.1:** IEEE 14 Bus Test Systems

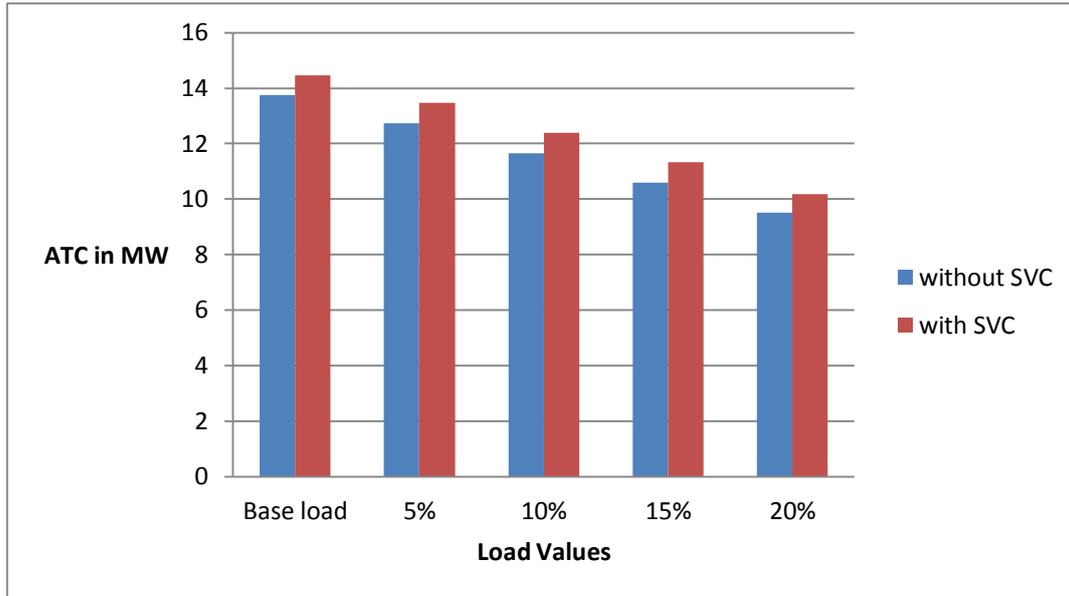
ATC in MW	Without SVC					With SVC				
	Base Load	5% Over Loaded	10% Over Loaded	15% Over Loaded	20% Over Loaded	Base Load	5% Over Loaded	10% Over Loaded	15% Over Loaded	20% Over Loaded
PSO	13.74	12.74	11.65	10.59	9.52	14.47	13.47	12.38	11.32	10.17
WIPSO	13.74	12.70	11.65	10.59	9.52	14.47	13.43	12.38	11.32	10.25

**Table 7. 2:** IEEE 30 Bus Test Systems

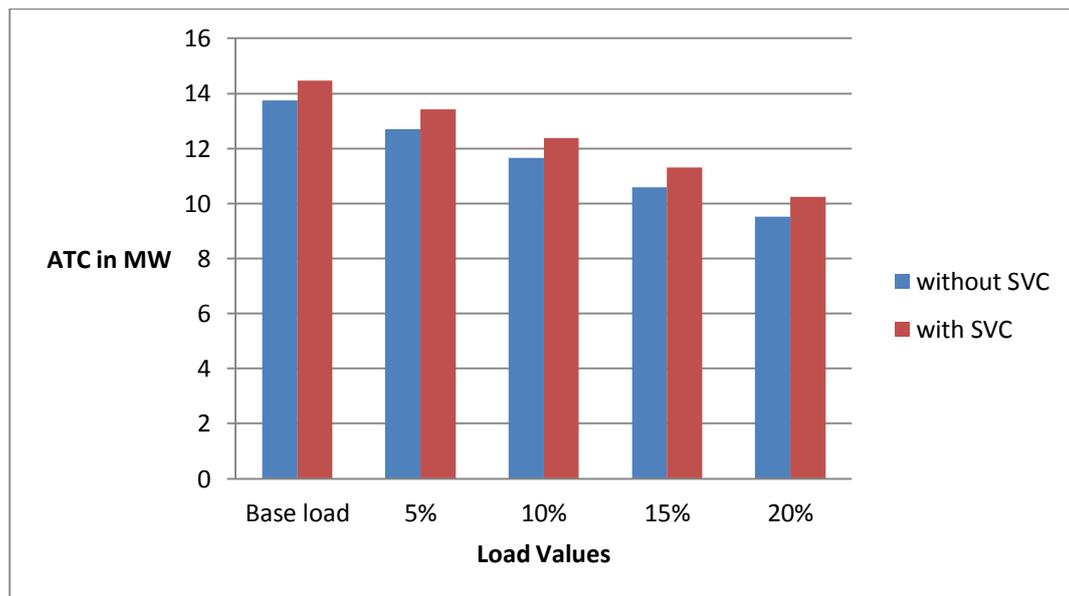
ATC in MW	Without SVC					With SVC				
	Base Load	5% Over Loaded	10% Over Loaded	15% Over Loaded	20% Over Loaded	Base Load	5% Over Loaded	10% Over Loaded	15% Over Loaded	20% Over Loaded
PSO	26.90	26.22	25.46	24.71	23.75	27.61	26.88	25.96	25.32	24.48
WIPSO	26.93	26.21	25.48	24.65	23.75	27.64	26.92	26.18	25.31	24.44

**Table 7. 3:** IEEE 57 Bus Test Systems

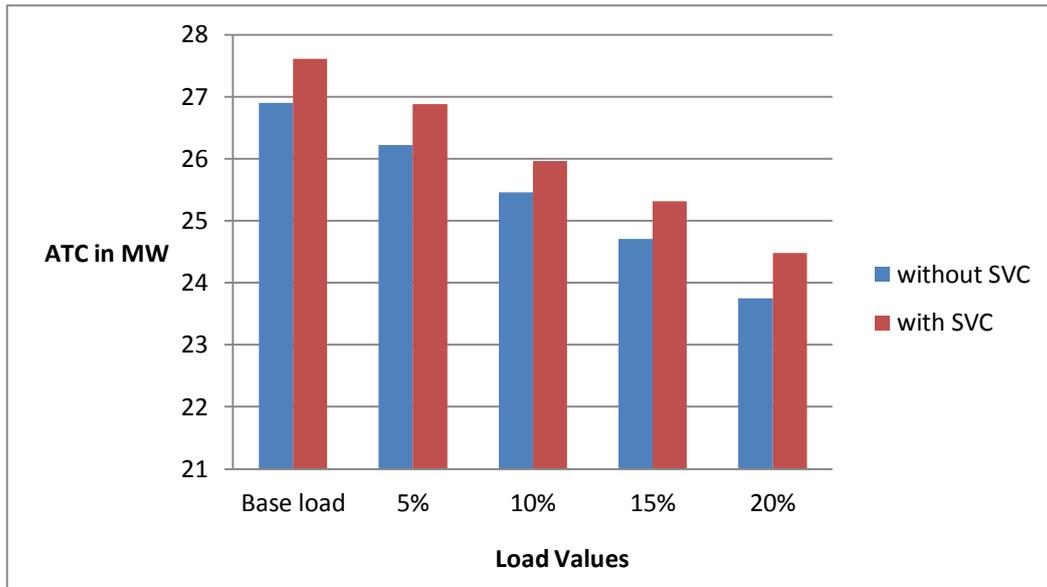
ATC in MW	Without SVC					With SVC				
	Base Load	5% Over Loaded	10% Over Loaded	15% Over Loaded	20% Over Loaded	Base Load	5% Over Loaded	10% Over Loaded	15% Over Loaded	20% Over Loaded
PSO	14.76	13.86	12.51	11.23	10.27	15.70	14.82	13.41	12.22	11.33
WIPSO	15.02	13.87	12.67	11.46	10.23	15.91	14.77	13.62	12.35	11.22



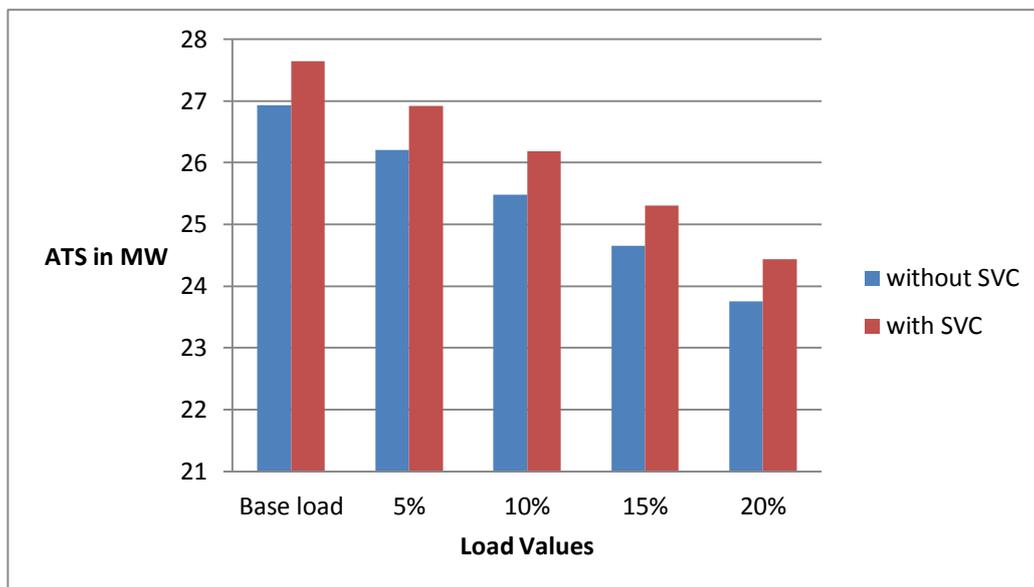
**Figure 7.1:** ATC VS percentage of load for IEEE 14 Bus Test systems (PSO)



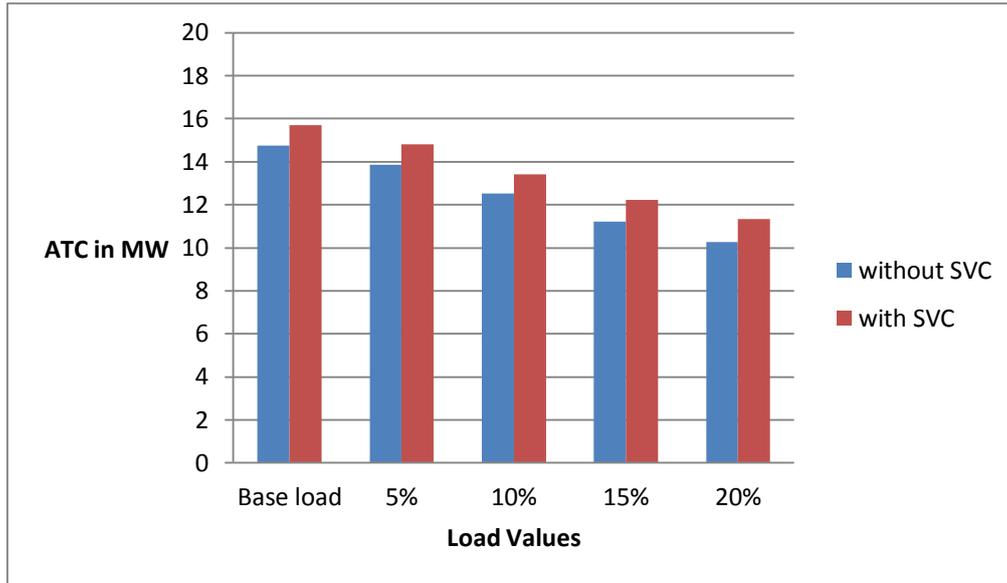
**Figure 7.2:** ATC VS percentage of load for IEEE 14 Bus Test systems (WIPSO)



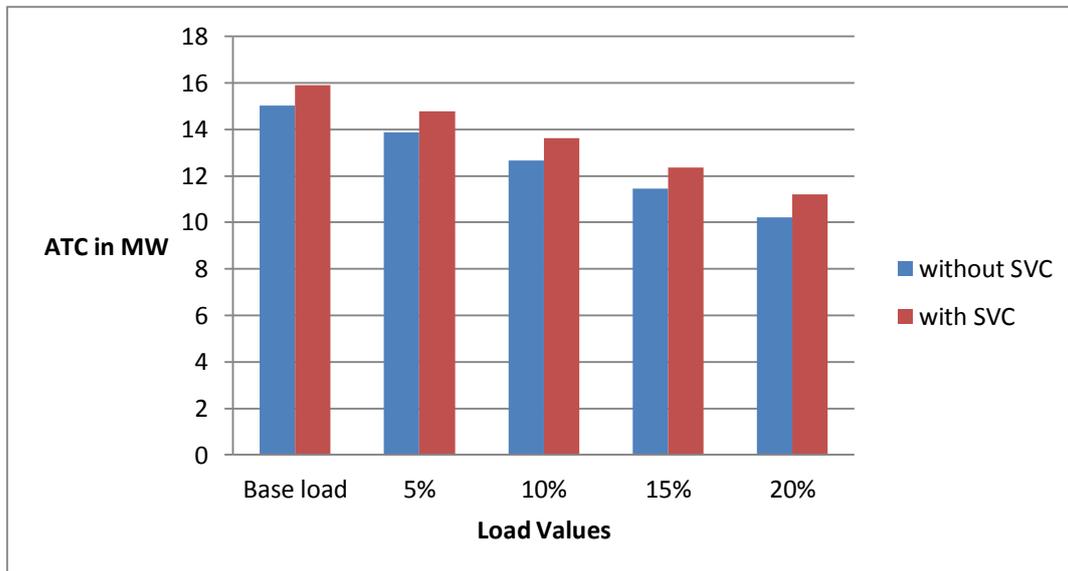
**Figure 7.3:** ATC VS percentage of load for IEEE 30 Bus Test systems (PSO)



**Figure 7.4:** ATC VS percentage of load for IEEE 30 Bus Test systems (WIPSO)



**Figure 7.5:** ATC VS percentage of load for IEEE 57 Bus Test systems (PSO)



**Figure 7.6:** ATC VS percentage of load for IEEE 57 Bus Test systems (WIPSO)

## Conclusion

PSO technique has been applied for solving the problem of ATC enhancement of power system for a bilateral transaction under CEED environment has been proposed wherein WIPSO technique has been used for choosing the optimum size and location of SVC under normal and various conditions. The results obtained were compared

against those obtained using PSO technique. The results clearly indicate that there is a considerable increase in the ATC of the lines after placing the SVC and due to the fact that the weight parameter, cognitive and social factors are adjusted in WIPSO to obtain a better global convergence, it shows a comparatively better performance than PSO. By applying this technique ATC of the systems can be enhanced for any of the wheeling transactions and a combination of devices may be used for a more flexible enhancement. This enhancement will improve the open access bidding and also promote competitive markets for electric power trading.

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