Placement of FACTS for Improving Total Transfer Capability, Reducing System Loss with Minimum Investment Cost Using Particle Swarm Optimization

Srinivasa Rao Kamala¹, Kalyan Kumar Boddeti²
Department of Electrical Engineering, Indian Institute of Technology Madras, India
srinu.kamala@gmail.com
Assistant Professor, Department of Electrical Engineering, Indian Institute of Technology Madras, India
bkalyn@ee.iitm.ac.in

Abstract — This paper presents two Flexible AC Transmission System (FACTS) devices, Static VAR Compensator (SVC) and Thyristor Controlled Series Capacitor (TCSC), are optimally placed to simultaneously minimize system real power loss, maximize the Total Transfer Capability (TTC) with minimum investment cost simultaneously, using Particle Swarm Optimization technique (PSO). The problem is divided into two parts. The first part is optimal placement of the SVC and TCSC using line loss sensitivity indices and the second part is to solve the multi-objective optimization of minimizing power loss, maximizing Total Transfer Capability (TTC) and minimizing the total investment cost of FACTS with system constraints like power balance, voltage limits and line thermal limits using PSO to calculate optimal SVC and TCSC parameters. The proposed method of optimal placement of FACTS devices is applied on New England 16-machine 68-bus system and the results are presented.

Keywords — FACTS, Multi objective optimization, Particle Swarm Optimization, Sensitivity index, SVC, TCSC, TTC.

I. INTRODUCTION

Flexible AC Transmission System (FACTS) devices are being utilized to achieve many objectives in an electric power system. FACTS technology is being promoted to extend the capacity of existing power transmission networks to their limits without the necessity of adding new transmission lines [1], [2]. This technology opens up new opportunities for controlling line power flows, minimizing losses, damp the inter area oscillations, increases the system stability and maintain bus voltages at desired level in a power system. These are achieved by controlling one or more of the system parameters like series impedance, shunt admittance, voltage at a bus and phase angle with the insertion of appropriate FACTS controllers in a power system network.

TTC is defined as the amount of electric power that can be transferred from one area to another over the interconnected transmission network in a reliable manner based on pre-contingency and post-contingency conditions [3]. Available Transfer Capability (ATC) is defined as a measure of the transfer capability, or available room in the physical transmission network, for transfers of power [3]. Various mathematical and optimization methods have been proposed to maximize TTC with and without FACTS devices. In [4] authors proposed continuation power flow for determining TTC, but it requires effective parameterization of predictor, corrector and step length to obtain solution. Also it requires more computational effort. Repeated power flow method is used [5] to determine ATC. Sensitivity based approach is proposed in [6] to optimally locate FACTS devices to enhance TTC. Predictor corrector primal dual interior point linear programming is used in [7] to enhance ATC using various FACTS devices. But in this work authors did not optimize FACTS devices ratings and locations. Sequential Quadratic Programming based method is proposed in [8] to find TTC incorporating the effect of reactive power but it requires the calculation of Hessian matrix in each iteration. For a large power system calculating Hessian matrix in each iteration may become computational burden and time consuming. Sequential quadratic programming proposed in [9] to calculate probabilistic TTC considering different contingency states requires second order derivative of the objective function.

Many algorithms have been proposed in the literature to place the FACTS devices optimally. Simulated Annealing (SA) and PSO techniques are used in [10] to minimize the losses. Genetic algorithm based method is proposed in [11] for minimizing the transmission loss. It requires external parameters such as cross over rate and mutation rate and the computational burden is high in this approach. Tabu search and Bees algorithms is proposed in [12], [13] to place the FACTS devices. But the drawback of the Bees algorithm is the excessive number of tunable parameters.

A new methodology is proposed to simultaneously minimize the transmission loss, improve the total transfer capability with minimum investment cost of the FACTS devices, by optimally placing the FACTS at a particular
location with optimal rating. In this work the FACTS devices considered are SVC and TCSC. Particle Swarm optimization based optimization method [14] has been used to solve the multi-objective optimization of minimizing power loss, maximizing TTC and minimizing the total investment cost of the FACTS devices with system constraints like power balance, voltage limits and line thermal limits. Constraints are handled using penalty function method described in [15]. The proposed method of optimally placing SVC and TCSC are applied to New England 16 machine 68 bus system and the results are presented. The results are compared with [11] which explains the optimal placement multiple FACTS devices using genetic algorithm.

II. OPTIMAL PLACEMENT AND RATING OF FACTS

To maximize TTC and minimize transmission losses using SVC and TCSC with minimum investment cost, SVC and TCSC need to be placed optimally and their rating should be decided. SVC and TCSC are first placed optimally in the system to improve TTC and reduce transmission losses through loss sensitivity index. Once SVC and TCSC is optimally placed their rating is found by solving a multi-objective optimization problem using PSO. The method of finding optimal placement and rating is explained below.

A. Optimal Placement of SVC

An optimal location for SVC has to be found in the system for minimizing the system losses. In this work system loss sensitivity [16], [17] with respect to the SVC control parameters has been used to optimally place SVC. The power loss in a transmission system and the loss sensitivity index with respect to the SVC control parameter is given in (1) and (2), respectively.

\[
P_{\text{Loss},n} = \sum_{j=1}^{n} \sum_{k=1}^{j-1} \left[ \alpha_{jk}(P_{jk} + Q_{jk}) + \beta_{jk}(Q_{jk} - P_{jk}) \right]
\]

\[
\frac{\partial P_{\text{Loss},n}}{\partial Q_{ij}} = 2 \sum_{j=1}^{n} (\alpha_{ij} + \beta_{ij})
\]

where,

\[
\alpha_{jk} = \frac{r_{jk} \cos(\delta_j - \delta_k)}{V_j V_k}
\]

\[
\beta_{jk} = \frac{r_{jk} \sin(\delta_j - \delta_k)}{V_j V_k}
\]

\[
\alpha_{jk}, \beta_{jk} : \text{are the loss co efficient}
\]

\[
P_j, P_k : \text{Real power injections at the buses } j \text{ and } k
\]

\[
Q_j, Q_k : \text{Reactive power injections at the buses } j \text{ and } k
\]

\[
V_j, V_k : \text{Voltage magnitudes at the buses } j \text{ and } k
\]

\[
r_{jk} : \text{Resistance of the transmission line connected between bus } i \text{ and } j
\]

\[
\delta_j, \delta_k : \text{Voltage phase angles at the buses } i \text{ and } j
\]

The bus having most negative sensitive index is the suitable location of SVC. The SVC should not be placed at the generator buses, even though the line sensitivity is high.

B. Optimal Placement of TCSC

An optimal location for TCSC has to be found in the system for minimizing the system losses. In present work system loss sensitivity [16], [17] with respect to the TCSC control parameters has been used to optimally place TCSC. The power loss in a line connected between buses \(i\) and \(j\) in transmission system and the loss sensitivity index with respect to the TCSC control parameter is given in (3) and (4), respectively.

\[
P_{\text{Loss},n} = \left( \frac{V_i^2 + V_j^2 - 2 V_i V_j \cos(\delta_i - \delta_j)}{r_n^2 + x_n^2} \right) r_n
\]

\[
\frac{\partial P_{\text{Loss},n}}{\partial x_{ij}} = 2 g_n b_n (V_i^2 + V_j^2 - 2 V_i V_j \cos(\delta_i - \delta_j))
\]

where,

\[
g_n = \frac{r_n}{r_n^2 + x_n^2}
\]

\[
b_n = \frac{-x_n}{r_n^2 + x_n^2}
\]

\[
V_i, V_j : \text{Voltage magnitudes at the buses } i \text{ and } j
\]

\[
r_n : \text{Resistance of the line connected between the buses } i \text{ and } j
\]

\[
x_n : \text{Reactance of the line including the TCSC}
\]

\[
\delta_i, \delta_j : \text{Voltage phase angles at the buses } i \text{ and } j
\]

\[
x_{ij} : \text{Reactance of line connected between buses } i \text{ and } j
\]

\[
g_n, b_n : \text{Conductance and susceptance of the line including TCSC}
\]

\[
x_{TCSC} : \text{Reactance of thyristor controlled series capacitor}
\]

The bus having most positive sensitive index is the suitable place for the device. The TCSC should not be placed between two generation buses, even though the line sensitivity is highest.

C. Total Transfer Capability Calculation

The objective is to maximize the power that can be transferred from generators in a system to loads subject to voltage limits, line flow limits and device operation limits. For calculating TTC, the injected real powers \(P_{Di}\) at source area, and load demands \(P_{Dj}\) at sink area are increased simultaneously to maximize loading factor, lambda \(\lambda\) in (5). The optimum value of \(\lambda\) is calculated using PSO technique.
Constraints are handled using penalty function method given in [15]. Equality constraints:

\[
\begin{align*}
    P_{Gi} - P_{Di} - \sum_{j=1}^{n} V_j V_j (g_{ij} \cos(\delta_i - \delta_j) + b_{ij} \sin(\delta_i - \delta_j)) &= 0 \\
    Q_{Gi} - Q_{Di} - \sum_{j=1}^{n} V_j V_j (g_{ij} \sin(\delta_i - \delta_j) - b_{ij} \cos(\delta_i - \delta_j)) &= 0
\end{align*}
\]

Inequality constraints:

\[
\begin{align*}
    P_{Gi}^{\min} &\leq P_{Gi} \leq P_{Gi}^{\max}, \ i = 1, 2, 3...n_G \\
    Q_{Gi}^{\min} &\leq Q_{Gi} \leq Q_{Gi}^{\max}, \ i = 1, 2, 3...n_G \\
    V_i^{\min} &\leq V_i \leq V_i^{\max}, \ i = 1, 2, 3...n_{\text{Load}} \\
    S_n &\leq S_n^{\max}, \ n = 1, 2, 3...n_{\text{Lines}}
\end{align*}
\]

where,
- \( \lambda \) : loading factor
- \( P_{Gi}, Q_{Gi} \) : Real and reactive power generations at bus \( i \)
- \( P_{Di}, Q_{Di} \) : Real and reactive power loads at bus \( i \)
- \( P^0, Q^0 \) : Base case real power injection.
- \( P^0_{Gi}, Q^0_{Gi} \) : Base case real and reactive power loads
- \( k_{Di}, k_{Gi} \) : Constant specify the rate of changes in load
- \( V_i, V_j \) : Voltage magnitudes at the buses \( i, j \)
- \( \delta_i, \delta_j \) : Voltage phase angles at the buses \( i, j \)
- \( P_{Gi}^{\min}, P_{Gi}^{\max} \) : Real power generation limits
- \( Q_{Gi}^{\min}, Q_{Gi}^{\max} \) : Reactive power generation limits
- \( V_i^{\min}, V_i^{\max} \) : Voltage minimum and maximum limits
- \( S_n^{\max} \) : Thermal limit of line \( n \)
- \( g_{ij}, b_{ij} \) : Conductance and susceptance of the line

Therefore the sum of real power loads in sink area at the maximum power transaction in (normal or contingency case) represents the TTC value.

\[
    TTC = \sum_{j=1}^{n_{\text{max}}} P_{Di}(\lambda_{\text{max}}) - \sum_{i=1}^{n_{\text{max}}} P^0_{Di}
\]  

D. Investment Cost of the FACTS Devices

Based on Siemens AG Database [18], the cost functions for SVC, TCSC, and UPFC are developed as follows

i. The cost function for SVC is:

\[
    C_{\text{SVC}} = 0.00035^2 - 0.03515 + 127.38 \ \text{US$/KVAR}
\]

ii. The cost function for TCSC is

\[
    C_{\text{TCSC}} = 0.00155^2 - 0.07130 + 153.75 \ \text{US$/KVAR}
\]

The total investment cost is the sum of the SVC cost and the TCSC cost given in (11)

\[
    C_{\text{TOTAL}} = C_{\text{SVC}} + C_{\text{TCSC}}
\]  

where \( S \) is the rating of the devices in MVAR

E. Optimal Rating of SVC and TCSC with minimum Investment cost to Minimize the Losses and Maximizing TTC

To calculate optimal rating of the devices, an objective function consisting of loss minimization, TTC enhancement and investment cost minimization is formulated and given in (12). Voltage limit violation at load buses, line thermal limit violation, reactive power generation violation at the generator buses are taken as the operational constraints and the SVC injected reactive power, TCSC injected reactive powers at the most sensitive buses are taken as the control variables.

\[
    F = \min(w_1^{\ast} \frac{P_{\text{loss}}}{\text{Base Loss}} + w_2^{\ast} \sum_{\text{TTC}} + w_3^{\ast} \frac{C_{\text{SVC}}}{BC_{\text{SVC}}} + w_3^{\ast} \frac{C_{\text{TCSC}}}{BC_{\text{TCSC}}})
\]

where,
- \( C_{\text{SVC}} \) : is the cost function of SVC in \$/KVAR
- \( C_{\text{TCSC}} \) : is the cost function of TCSC in \$/KVAR
- \( BC_{\text{SVC}} \) : is the cost of 500 MVAR SVC
- \( BC_{\text{TCSC}} \) : is the cost of 0.0275 p. u. TCSC

Equality constraints:

\[
\begin{align*}
    P_{Gi} - P_{Di} - \sum_{j=1}^{n} V_j V_j (g_{ij} \cos(\delta_i - \delta_j) + b_{ij} \sin(\delta_i - \delta_j)) &= 0 \\
    Q_{Gi} - Q_{Di} - \sum_{j=1}^{n} V_j V_j (g_{ij} \sin(\delta_i - \delta_j) - b_{ij} \cos(\delta_i - \delta_j)) &= 0
\end{align*}
\]

Inequality constraints:

\[
\begin{align*}
    P_{Gi}^{\min} &\leq P_{Gi} \leq P_{Gi}^{\max}, \ i = 1, 2, 3...n_G \\
    Q_{Gi}^{\min} &\leq Q_{Gi} \leq Q_{Gi}^{\max}, \ i = 1, 2, 3...n_G \\
    V_i^{\min} &\leq V_i \leq V_i^{\max}, \ i = 1, 2, 3...n_{\text{Load}} \\
    S_n &\leq S_n^{\max}, \ n = 1, 2, 3...n_{\text{Lines}}
\end{align*}
\]

Where base loss is the system loss and the base TTC are the system loss and TTC respectively without the FACTS devices. Penalty functions include the voltage violation at the load buses, line thermal limits and active and reactive power generation violations at the generator buses. \( w_1, w_2, w_3 \) and \( w_4 \) are weighing factors to set the relative importance for the
four objective functions given in (12). In this work equal importance is given to the first two objectives that is minimization of losses and maximization of TTC, the weights are chosen as 0.4 and less importance given to the objectives SVC and TCSC cost minimization and the weights are chosen as 0.1. PSO has been used for solving the multi-objective function given in (12). The static models of SVC and TCSC are explained in detail in the next section.

III. STEADY STATE MODELLING OF FACTS

A. Steady State Modelling of SVC

In order to improve the total transfer capability and to minimize the transmission loss by using SVC, the static model of the SVC as shown in Fig. 1 has been considered.

![Fig.1: Static VAR compensator](Image)

The SVC consists of a fixed capacitor and a thyristor controlled reactor (TCR) connected in parallel. SVC is connected in shunt with the bus. The equivalent reactance of TCR at the fundamental frequency \( X_{TCR} \) is given as

\[
X_{TCR} = \frac{\pi X_L}{2(\pi - \alpha) + \sin 2\alpha}
\]

where,

\[ \alpha = \pi - \frac{\sigma}{2} \quad \text{and} \quad X_L = \omega L \]

\( \alpha \): Firing angle of the thyristor

\( \sigma \): Conduction angle of the thyristor

At \( \alpha = 90^\circ \) TCR conducts fully and the equivalent reactance \( X_{TCR} \) becomes \( X_L \), while at \( \alpha = 180^\circ \), TCR is blocked and its equivalent reactance becomes infinite. The equivalent reactance of SVC at the fundamental frequency \( X_{SVC} \) is the parallel combination of capacitive reactance and the TCR reactance and the reactance in terms of angle \( \alpha \) is given as

\[
X_{SVC} = \frac{\pi X_C X_L}{X_C[2(\pi - \alpha) + \sin 2\alpha] - \pi X_L}
\]

where,

\[ \alpha = \pi - \frac{\sigma}{2} \quad \text{and} \quad X_L = \omega L \]

\( X_C = \frac{1}{\omega C} \), \( X_L = \omega L \)

\( \sigma \): Conduction angle of the thyristor

\( \alpha \): Firing angle of the thyristor

\( X_C \), \( X_L \): Inductive reactance and capacitive reactance

B. Steady State Modelling of TCSC

The static model of the TCSC as shown in Fig. 2 has been considered in this work.

![Fig.2: Thyristor controlled series capacitor](Image)

The TCSC consists of a capacitor bank and a thyristor controlled reactor (TCR) connected in parallel and it is connected in series with the transmission line. The effect of the TCSC on network can be seen as a controllable reactance inserted in a transmission line. The effective reactive admittance of TCR at fundamental frequency \( B_{TCR}(\alpha) \) is given in (17). The equivalent reactance of TCSC at the fundamental frequency is the parallel combination of capacitive reactance and the TCR reactance is given by (18). The power balance equations after including TCSC are given in (19).

\[
B_{TCR}(\alpha) = \frac{1}{X_L}(1 - \frac{2}{\pi} \alpha - \frac{1}{\pi} \sin 2\alpha) \quad (17)
\]

\[
X_{TCSC}(\alpha) = \frac{X_C X_L}{\pi X_C[2(\pi - \alpha) + \sin(2\alpha)] - X_L} \quad (18)
\]

The power flow equations with TCSC is given by

\[
P_{ij} = V_i^2 g_{ij} - V_i V_j \left( g_{ij} \cos(\delta_i - \delta_j) + b_{ij} \sin(\delta_i - \delta_j) \right)
\]

\[
Q_{ij} = -V_i^2 b_{ij} - V_i V_j \left( g_{ij} \sin(\delta_i - \delta_j) - b_{ij} \cos(\delta_i - \delta_j) \right)
\]

where,

\[ g_{ij} = \frac{r_{ij}}{r_{ij}^2 + (x_{ij} + X_{TCSC})^2} \]

\[ b_{ij} = -\frac{x_{ij} + X_{TCSC}}{r_{ij}^2 + (x_{ij} + X_{TCSC})^2} \]

\( X_{TCSC} \): Reactance of the TCSC

\( \alpha \): Firing angle of the thyristor

\( X_C \), \( X_L \): Inductive reactance and capacitive reactance

\( V_i, V_j \): Voltage magnitudes at the buses \( i \) and \( j \)

\( P_{ij}, Q_{ij} \): Real and reactive power injections in line.
$r_{ij}, x_{ij}$ : Resistance and reactance of the line connected between the buses $i$ and $j$

$b_{ij}, b_{ij}$ : Conductance and susceptance of the line connected between buses $i$ and $j$.

IV. PARTICLE SWARM OPTIMIZATION

The PSO is a population-based optimization method first proposed by Kennedy and Eberhart [9]. The PSO is best suitable for optimizing non-smooth and non-linear functions as compared to classical methods like gradient search. It also has the advantage of not being stuck to a local minimum. The PSO is a population-based optimization technique that is originally inspired by the sociological behaviour associated with bird flocking and fish schooling. It is used to find a solution to an optimization problem in a search space and predict behaviour of all particles in the presence of various constraints and objectives.

Each particle is characterized by its position and velocity. In each iteration, the velocity of each particle is modified using its current velocity and its distance from personal best position “pbest” and global best position “gbest” according to equation given in (20),

$$v^{k+1}_i = wv^k_i + c_1 * rand() * (pbest_i - s^k_i) + c_2 * rand() * (gbest_i - s^k_i)$$

(20)

where,

$w$ : Inertia weight

$c_1, c_2$ : Acceleration coefficients

$v^k_i$ : $i^{th}$ dimension velocity component at $k^{th}$ iteration

$s^k_i$ : Current position in the $i^{th}$ dimension at $k^{th}$ iteration

$rand()$ : Random number generator between 0 and 1

$pbest_i$ : Personal best position value in the $i^{th}$ dimension

$gbest_i$ : Global best position value in the $i^{th}$ dimension

After the velocity update is done, each particle is allowed to explore the search space of the problem for a better solution as given in (21)

$$s^{k+1}_i = s^k_i + v^{k+1}_i$$

(21)

In (20), the first term represents the particle’s current velocity. The second term represents the cognitive part of velocity, while the third term represents the social interactive part of the velocity. The personal best position of each particle is updated after the $k^{th}$ iteration as given in (22)

$$pbest = \begin{cases} s & \text{iff } f(s) \leq f(pbest) \\ pbest & \text{iff } f(s) > f(pbest) \end{cases}$$

(22)

Where, ‘f’ is the fitness function. The global best position among the particles personal best position is updated after the $k^{th}$ iteration as given in (23).

$$gbest = \begin{cases} pbest & \text{iff } f(pbest) \leq f(gbest) \\ gbest & \text{iff } f(pbest) > f(gbest) \end{cases}$$

(23)

The main advantage of PSO is that it will converge to the global minimum without becoming trapped at local minimum.

V. SIMULATION RESULTS

The proposed algorithm is applied on New England 16-Machine, 68 bus system [18]. Fig. 3 represents 5 area New England 16-machines, 68-bus test system. Simulations are done in two steps. First step is to find the optimal location of SVC and TCSC and the second step is to find the parameters of the SVC and TCSC by solving multi objective problem given in (21) using PSO.
Placement of FACTS for Improving Total Transfer Capability, Reducing System Loss with Minimum Investment Cost Using Particle Swarm Optimization

Fig. 3: Single line diagram of 16-machine, 68-bus test system

VC is placed using loss sensitivity index given in (2). Fig. 4 shows the bus number versus power loss sensitivity plot given in (2).

![SVC loss sensitivity index](image)

Fig. 4: SVC loss sensitivity index

It can be observed from Fig. 4 that 39th bus is the most negative sensitive bus and it is the best location to place the SVC to reduce the transmission loss. TCSC is placed using line loss sensitivity index given in (4). Fig. 5 shows the line number versus power loss sensitivity plot given in (4).

![TCSC loss sensitivity index](image)

Fig. 5: TCSC loss sensitivity index

It can be observed from Fig. 5 that 16th line is the most positive sensitive line and it is the best location to place the device to reduce the transmission loss.
For the proposed system the total transfer capability that is the power that can be transferred from all generators to loads without placing the SVC and TCSC is 26,582 MW with a loading factor of 1.4423. To calculate the TTC with the FACTS devices, we need to place devices at the optimal location. After performing the simulations to place the devices in the system to improve TTC it was observed that the most negative sensitivity bus that is 39th bus and most positive sensitivity line that is 16th line are the best suitable locations for the SVC and TCSC respectively.

Next problem is to include SVC and TCSC in the system and find the ratings of the devices to minimize the system loss, maximize the TTC with minimum investment cost of the SVC and TCSC as given in (12) using PSO. The PSO parameters considered for the simulation work are, acceleration coefficients c1 and c2 are equal to 1.49, maximum and minimum inertia weights are 0.9 and 0.4 respectively. Number of particles used for simulation are 100 and the number of generations are 50. The objective function (21) consisting of active power loss, TTC and the cost of the SVC and the TCSC as the objectives with the line thermal limits, power generation at the generator buses and the bus voltage limits at the load buses as the constraints. Line thermal limit is taken as 30% more than the base case loading and the bus voltage limits are 0.9 to 1.1 p. u. The weighting factors corresponding to the individual objective functions are w1, w2, w3 and w4 and the values are 0.4, 0.4, 0.1 and 0.1 respectively. In the present work objectives active power loss reduction and TTC has been given more importance compared to the cost of the devices. Fig. 5 represents the convergence of the fitness function with number of generations.

![Fitness function](image)

**Fig. 6: Convergence of the fitness function**

It was observed from the figure that the function converges after 22 iterations. Table 2 gives the loss and TTC values with and without SVC and TCSC. It can be observed from Table 2 that with the proposed method of optimal placement and rating of SVC and TCSC, the loss has reduced by 17.86 MW and TTC increased by 1871 MW, approximately. The ratings of the SVC and TCSC are 346.46 MVAR and 449.9 MVAR with a cost of 57,663 US$/MVAR and 61,470 US$/MVAR respectively. This clearly shows the effectiveness of the proposed method.

<table>
<thead>
<tr>
<th>Objective</th>
<th>Without SVC, TCSC</th>
<th>With SVC, TCSC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimizing Loss and maximizing TTC with minimum investment cost</td>
<td>Loss (MW)</td>
<td>288.56</td>
</tr>
<tr>
<td></td>
<td>TTC (MW)</td>
<td>26,582</td>
</tr>
</tbody>
</table>

Table 2: Loss and TTC enhancement using SVC and TCSC

The results are compared with [11] and given in table 3. Author proposed Genetic Algorithm based optimal placement of multiple FACTS devices to maximize the total transfer capability and simulations done on modified IEEE 118 bus and 187 line test system. Without placing the SVC and TCSC the maximum power that can transferred from all generator to loads is 3651 MW, placing one SVC at 43rd bus the loading factor is increased by 1.02 that is TTC is increased to 3724 MW and by placing one TCSC in the line connected between the buses 5 and 8 the loading factor is increased by 1.08 that is TTC in increased by 3943 MW approximately and the method improves the TTC by 9.8%. In the present work with the proposed method by solving the objective function consisting TTC as the objective, using PSO by placing SVC and TCSC at 39th bus and 14th line TTC is improved to 29,567 MW that is TTC is improved by 11.10 % and The ratings of the SVC and TCSC are 376.23 MVAR and 526.3 MVAR.

<table>
<thead>
<tr>
<th>Objective</th>
<th>TTC without SVC, TCSC (MW)</th>
<th>TTC with SVC, TCSC (MW)</th>
<th>Percentage Improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modified IEEE 118 - bus system</td>
<td>3,651</td>
<td>4,016</td>
<td>9.91</td>
</tr>
<tr>
<td>New England 68 - bus system</td>
<td>26,582</td>
<td>29,567</td>
<td>11.1</td>
</tr>
</tbody>
</table>

Table 3: Results comparison with IEEE 118 bus test system

VI. CONCLUSIONS

The In this paper a new method was proposed for simultaneously placing SVC and TCSC optimally to minimize the power loss, maximize the total transfer capability with minimum investment cost using Particle Swarm Optimization. The proposed method was applied to

1077
New England 16 machine 68 bus system and the results were presented. It was observed from the results that with the optimal location and ratings of SVC and TCSC, the real power losses have reduced and the TTC has increased as compared to no SVC and TCSC case. This clearly demonstrates the effectiveness of the proposed method.

REFERENCES


http://www.ieejournal.com/