

# Enhancement of Total Transfer Capability by Particle Swarm Optimization

K. S. Pandya<sup>a,\*</sup>, S. K. Joshi<sup>b</sup>

<sup>a</sup> Electrical Engineering Department, Charotar Institute of Technology, Changa-388 421, Gujarat, INDIA  
E-mail address: kartik\_pandya@rediffmail.com, Phone No. +91 2692 247600

<sup>b</sup> Electrical Engineering Department, The Maharaja Sayajirao University of Baroda, Post box No. 51, Vadodara-390 002, Gujarat, INDIA. E-mail address: skjoshi@ieee.org

**Abstract**—In this article, a Particle Swarm Optimization (PSO) based method has been suggested to find the optimal location and setting of Thyristor Controlled Series Compensator (TCSC) for simultaneously maximizing the Total Transfer Capability (TTC) and minimizing total real power losses of deregulated electricity markets consisting of bilateral and multilateral transactions. While solving multi-objective OPF, various inequality constraints have been handled by penalty function. The robustness of the proposed algorithm has been tested on IEEE 30 bus system. PSO gives accurate results which may be used for online TTC calculation at the energy management centre.

**Key words**— Competition, Particle swarm optimization, Thyristor controlled series compensator, Total transfer capability

## 1. INTRODUCTION

Total Transfer Capability (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 [1]. In recent time, electrical supply systems of many countries have been transformed from monopolistic nature to competitive structure to increase efficiency, reliability, stability and to reduce cost. In this new era, there should be sufficient TTC to fulfill scheduled transactions between the buyers and sellers and to provide non-discriminatory open access to market participants. Also, TTC and ATC [1] are calculated between a pair of areas and they are posted on Open Access Same-time Information System (OASIS) to make competition effective.

Large increase in power demand, competition and scarce natural resources are some factors due to which transmission systems operate very near to their thermal limits. But because of economic, environmental and political reasons it is not preferable to build new transmission lines. So there is an interest in better utilization of existing capacities of power system by installing Flexible A.C. Transmission System (FACTS) device such as

Thyristor Controlled Series Compensator [2]. FACTS are the power electronics based converter-inverter circuits which can enhance TTC, voltage stability, loadability, security etc. and can reduce losses, production cost of generation, can remove congestion and fulfill transaction requirement rapidly and efficiently.

Due to the following two reasons it is necessary to “optimally” locate FACTS devices in order to obtain their full benefits. (1) They are costly devices, (2) They may have negative effects on system stability unless they are optimally placed [3].

### 1.1 Literature survey

Various mathematical and optimization methods have been proposed to maximize TTC/ATC with and without FACTS devices.

G.C. Ejebe et al. [4] proposed continuation power flow for determining hourly TTC and ATC but It requires effective parameterization of predictor, corrector and step length to obtain solution. The computational effort required is large. M.H.Gravener et al [5] used repeated power flow method to determine ATC. It is simple method but it does not optimize generator output power and its voltage. K.S.Verma et al [6] proposed sensitivity based approach to optimally locate FACTS devices to enhance TTC. Ying Xiao et al [7] used predictor corrector primal dual interior point linear programming to enhance ATC using various FACTS devices. However it did not optimize their ratings and locations. M. Shaaban et al [8] proposed SQP based method to find TTC incorporating the effect of reactive power but it requires the calculation of Hessian matrix in each iteration which is time consuming. Weixing Li et al [9] used sequential quadratic programming to calculate probabilistic TTC considering different contingency states. But this method requires second order derivative of the objective function. P. Jirapong et al [10] proposed hybrid evolutionary algorithm to optimally place TCSC, TCPS, UPFC and SVC to maximize TTC.

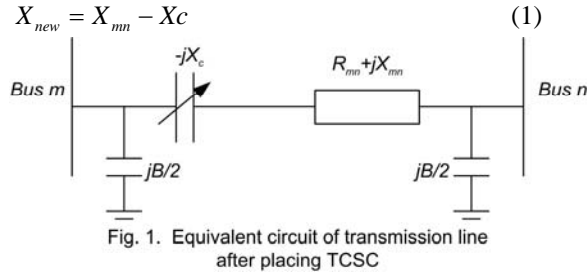
From the literature survey it is revealed that optimal placement of FACTS is highly nonlinear and nonconvex optimization problem which can not be effectively solved by classical methods as they may get trapped into local minima or diverge at all. To solve such problem, recently invented Artificial

Intelligence method called Particle Swarm Optimization [11] can be used as it is fast and provides global solution. PSO has shown its superiority over other classical and AI methods with respect to execution time and global solution in solving economic dispatch problem [12] and optimal reactive power dispatch problem [13].

So in this article, PSO based algorithm has been suggested to find the best location and setting of TCSC to maximize TTC and to minimize losses of the competitive electricity markets consisting of bilateral and multilateral transactions under normal and contingency states.

## 2. MODELING OF TCSC

As shown in Fig. 1, the TCSC has been represented by a variable capacitive/inductive reactance inserted in series with the transmission line [15]. So the reactance of the transmission line is adjusted by TCSC directly. Let,  $X_{mn}$  is the reactance of the transmission line,  $X_c$  is the reactance of TCSC and  $X_{new}$  is the new reactance of the line after placing TCSC between bus m and n. Mathematically, equation is written as:



The modified power flow equations of the transmission line in the presence of TCSC are given as below:

$$P_{mn} = V_m^2 G_{mn} - V_m V_n (G_{mn} \cos \delta_{mn} + B_{mn} \sin \delta_{mn}) \quad (2)$$

$$Q_{mn} = -V_m^2 \left( B_{mn} + \frac{B}{2} \right) - V_m V_n (G_{mn} \sin \delta_{mn} - B_{mn} \cos \delta_{mn}) \quad (3)$$

$$P_{nm} = V_n^2 G_{mn} - V_m V_n (G_{mn} \cos \delta_{mn} - B_{mn} \sin \delta_{mn}) \quad (4)$$

$$Q_{nm} = -V_n^2 \left( B_{mn} + \frac{B}{2} \right) + V_m V_n (G_{mn} \sin \delta_{mn} + B_{mn} \cos \delta_{mn}) \quad (5)$$

where,

$$G_{mn} = \frac{R_{mn}}{R_{mn}^2 + (X_{mn} - X_c)^2}, B_{mn} = \frac{-(X_{mn} - X_c)}{R_{mn}^2 + (X_{mn} - X_c)^2}$$

$P_{mn}, Q_{mn}$ : Active and reactive power flow from bus m to n

$P_{nm}, Q_{nm}$ : Active and reactive power flow from bus n to m

$G_{mn}$ : New line conductance between bus m and n

$B_{mn}$ : New line susceptance between bus m and n

$R_{mn}$ : Line resistance between bus m and n

## 3. PROBLEM FORMULATION

A multi-objective optimal power flow given by P. Jirapong et al.[10] is used to optimally locate TCSC for maximizing TTC and minimizing total real power loss, subject to satisfy various equality and inequality constraints. The OPF is given in (6).

$$\text{Max} \{ K_1 \times \sum_{m=1}^{LOAD\_SINK} P_{Dm} - K_2 \times \sum_{r=(m,n), r \in N_L}^{N_L} (P_{mn} + P_{nm}) - PF \} \quad (6)$$

Subject to the power balance equations (equality constraints)

$$\begin{cases} P_{Gm} - P_{Dm} - \sum_{n=1}^{N_b} |V_m| |V_n| |Y_{mn}| \cos(\delta_m - \delta_n - \theta_{mn}) = 0 \\ Q_{Gm} - Q_{Dm} - \sum_{n=1}^{N_b} |V_m| |V_n| |Y_{mn}| \sin(\delta_m - \delta_n - \theta_{mn}) = 0 \end{cases} \quad (7)$$

Various operating constraints (inequality constraints)

$$P_{Gm}^{\min} \leq P_{Gm} \leq P_{Gm}^{\max}, m \forall N_G \quad (8)$$

$$Q_{Gm}^{\min} \leq Q_{Gm} \leq Q_{Gm}^{\max}, m \forall N_G \quad (9)$$

$$|S_l| \leq S_l^{\max}, l \forall N_L \quad (10)$$

$$V_m^{\min} \leq V_m \leq V_m^{\max}, m \forall N_b \quad (11)$$

$$X_c^{\min} \leq X_c \leq X_c^{\max} \text{ p.u.} \quad (12)$$

where,

$k_1, k_2$ : Constants in the range  $[10^3, 10^8]$

$LOAD\_SINK$ : Total number of load buses in sink area

$\sum_{m=1}^{LOAD\_SINK} P_{Dm}$ : TTC value

$\sum_{r \in N_L}^{N_L} (P_{mn} + P_{nm}) = P_{loss}$ : Total real power loss of the transmission system

$PF$ : Penalty Function

$P_{Gm}, Q_{Gm}$ : Active and reactive power generation at bus m

$P_{Dm}, Q_{Dm}$ : Active and reactive power demand at bus m

$|V_m| \angle \delta_m$ : Complex voltage at bus m

$|Y_{mn}| \angle \theta_{mn}$ :  $mn^{\text{th}}$  element of bus admittance matrix

$P_{Gm}^{\min}, P_{Gm}^{\max}$ : Active power generation limits at bus m

$Q_{Gm}^{\min}, Q_{Gm}^{\max}$ : Reactive power generation limits at bus m

$S_l^{\max}$ : Thermal limit of  $l^{\text{th}}$  transmission line

$V_m^{\min}, V_m^{\max}$ : Voltage magnitude limits at bus m

$X_c^{\min} = -0.85 \times X_{mn}$ : Lower limit of reactance of TCSC

$X_c^{\max} = 0.2 \times X_{mn}$ : Upper limit of reactance of TCSC

$N_L$ : Total number of transmission lines

$N_b$ : Total number of buses

$N_G$ : Total number of generator buses

Square penalty function is used to handle inequality constraints such as reactive power output of generator buses, voltage magnitude of all buses and transmission lines thermal limits as shown in (13) and (14).

$$PF = k_3 \times \sum_{m=1}^{N_G} f(Q_{Gm}) + k_4 \times \sum_{m=1}^N f(V_m) + k_5 \times \sum_{m=1}^{N_L} f(S_{lm}) \quad (13)$$

$$f(x) = \begin{cases} 0 & \text{if } x^{\min} \leq x \leq x^{\max} \\ (x - x^{\max})^2 & \text{if } x > x^{\max} \\ (x^{\min} - x)^2 & \text{if } x < x^{\min} \end{cases} \quad (14)$$

where,

$k_3, k_4, k_5$ : Penalty coefficients for reactive power output of generator buses ( $Q_{Gm}$ ), voltage magnitude ( $V_m$ ) of all buses and transmission line loading ( $S_{lm}$ ), respectively. Their values exist in the range  $[10^8, 10^{10}]$ .

$x^{\min}, x^{\max}$ : Minimum and maximum limits of variable  $x$ .

#### 4. MODELING OF BILATERAL AND MULTILATERAL TRANSACTIONS

A bilateral transaction is made directly between a seller and a buyer without any third party intervention. Mathematically, each bilateral transaction between a seller at bus  $m$  and buyer at bus  $n$  satisfies the following power balance relationship:

$$P_{Gm} - P_{Dn} = 0 \quad (15)$$

A multilateral transaction is a trade arranged by energy brokers and involves more than two parties. It may take place between a group of sellers and a group of buyers at different nodes.

$$\sum_{m \in \text{SELLER}} P_{Gm} - \sum_{n \in \text{BUYER}} P_{Dn} = 0 \quad (16)$$

where:

$P_{Gm}$ : Active power generation at bus  $m$  in a source area

$P_{Dn}$ : Active power demand at bus  $n$  in a sink area

**SELLER**: A group of seller buses which sell power to the buyers

**BUYER**: A group of buyer buses which buy power from the sellers.

Contingency analysis has been also carried out to study the impact of severe contingencies on the value of feasible TTC.

$$\text{Feasible TTC} = \min_n \{TTC_{IN}, TTC_{CON}^n\} \quad (17)$$

where,

$TTC_{IN}$ : Max. power transfer in system intact condition without considering any contingency

$TTC_{CON}^n$ : Max. power transfer under  $n^{th}$  contingency.

#### 5. PARTICLE SWARM OPTIMIZATION

PSO is a fast, simple and efficient population-based optimization method which was proposed by Eberhart and Kennedy. It has been motivated by the behavior of organisms such as fish schooling and bird flocking. In PSO, a "Swarm" consists of number of particles which represent the possible solutions. The coordinates of each particle is associated with two vectors, namely the position ( $x_i$ ) and velocity ( $v_i$ ) vectors. The size of both vectors is same as that of the problem space dimension. All particles in a swarm fly in the search space to explore optimal solutions. Each particle updates its position based upon its own best position, global best position among particles and its previous velocity vector according to the following equations:

$$v_i^{k+1} = w \times v_i^k + c_1 \times r_1 \times (p_{best_i} - x_i^k) + c_2 \times r_2 \times (g_{best} - x_i^k) \quad (18)$$

$$x_i^{k+1} = x_i^k + \chi \times v_i^{k+1} \quad (19)$$

where,

$v_i^{k+1}$ : The velocity of  $i^{th}$  particle at  $(k+1)^{th}$  iteration

$w$ : Inertia weight of the particle

$v_i^k$ : The velocity of  $i^{th}$  particle at  $k^{th}$  iteration

$c_1, c_2$ : Positive constants having values between  $[0, 2.5]$

$r_1, r_2$ : Randomly generated numbers between  $[0, 1]$

$p_{best_i}$ : The best position of the  $i^{th}$  particle obtained based upon its own experience

$g_{best}$ : Global best position of the particle in the population

$x_i^{k+1}$ : The position of  $i^{th}$  particle at  $(k+1)^{th}$  iteration

$x_i^k$ : The position of  $i^{th}$  particle at  $k^{th}$  iteration

$\chi$ : Constriction factor. It may help in sure convergence. Its low value facilitates fast convergence and little exploration while high value results in slow convergence and much exploration.

If no restriction is imposed on the maximum velocity ( $v_{max}$ ) of the particles then there is likelihood that particles may leave the search space. So velocity of each particle is controlled between  $(-v_{max})$  to  $(v_{max})$ .

#### 6. ALGORITHM TO OPTIMALLY LOCATE TCSC FOR MAXIMIZING TTC AND MINIMIZING LOSSES USING PSO.

(i) Input the data of lines, generators, buses and loads. Choose population size of particles and convergence criterion. Define type of power transaction.

(ii) Select reactance setting and location of TCSC as control variables.

(iii) Randomly generate population of particles such that their variables exist in their feasible range.

- (iv) Randomly install one TCSC in a transmission line and check that TCSC is not employed on the same line more than once in each iteration. Modify the bus admittance matrix.
- (v) Run full a.c. Newton-Raphson load flow to get line flows, active power generations, reactive power generations, line losses and voltage magnitude of all buses.
- (vi) Calculate the penalty functions of all particles using eqn. (13)
- (vii) Calculate the fitness functions of all particles using eqn. (6)
- (viii) Find out the “global best” ( $g_{best}$ ) particle having maximum value of fitness function in the population and “personal best” ( $p_{best_i}$ ) of all particles.
- (ix) Generate new population using eqns. (18) and (19).
- (x) Depending upon the type of power transaction, increase the unit power generations at selected generator buses and increase loads at selected load buses keeping load power factor constant.
- (xi) Go to step no. (iv) until maximum number of iterations are completed.
- (xii) Fitness value of  $g_{best}$  particle is the optimized (maximized) value of TTC and minimized value of losses. Coordinates of  $g_{best}$  particle give optimal setting and location of TCSC respectively.

## 7. RESULTS AND DISCUSSIONS

The IEEE 30 bus system has been used to demonstrate suitability of the proposed algorithm. The simulation studies were carried out on Pentium:IV, 512 MB of RAM, 1.8 GHz system in MATLAB 7.1 platform.

The bus, line and generator data is taken from MATPOWER [16]. It consists of 6 generators and 41 transmission lines. The system is partitioned into three areas as shown in Fig. 2. Two transactions namely a bilateral transaction between a seller bus no. 2 in source area to buyer bus no. 21 in sink area and a multilateral transaction between area 3 (seller bus-3,4) to area 2 (buyer bus-12,14,15,16,17,18,19 and 20) with the three objective functions i.e. (i) simultaneously maximize TTC and minimize active power loss ( $P_{loss}$ ), (ii) maximize only TTC and (iii) minimize only active power loss, have been considered.

Table 1 shows the test results of bilateral transaction from bus 2 to bus 21. Optimized values of TTC, real power loss, TCSC setting and TCSC location are indicated in bold letters. Case 1A shows the results of simultaneous maximization of TTC and minimization of active power loss. The base case load at bus 21 is

17.50 MW. TTC is 26.50 MW without installing TCSC, whereas after installing TCSC it is increased to 32.50 MW without violating system constraints. Active power loss is 3.60 MW without placing TCSC, but it is reduced to 3.58 MW after placing TCSC. Optimal location of TCSC is line no: 36, which is connected between bus 28 to bus 27 and optimal reactance of TCSC is -0.3360 p.u. Negative sign indicates that TCSC operates in capacitive mode. Limiting condition is the reactive power upper limit violation of generator G3, if further transaction takes place. Case 1B shows the results of maximization of TTC only. TTC can be improved from 26.50 MW to 33 MW after placing TCSC. TCSC setting, location and limiting conditions are same as that of case 1A. Case 1C shows the results of minimization of loss only. Base case TTC is 17.50 MW.  $P_{loss}$  is 2.99 MW without placing TCSC, but it is reduced to 2.84 MW after placing TCSC. TCSC also has great influence in reducing reactive power loss ( $Q_{loss}$ ). It reduces  $Q_{loss}$  from 10.74 MVAR to 10.30MVAR.

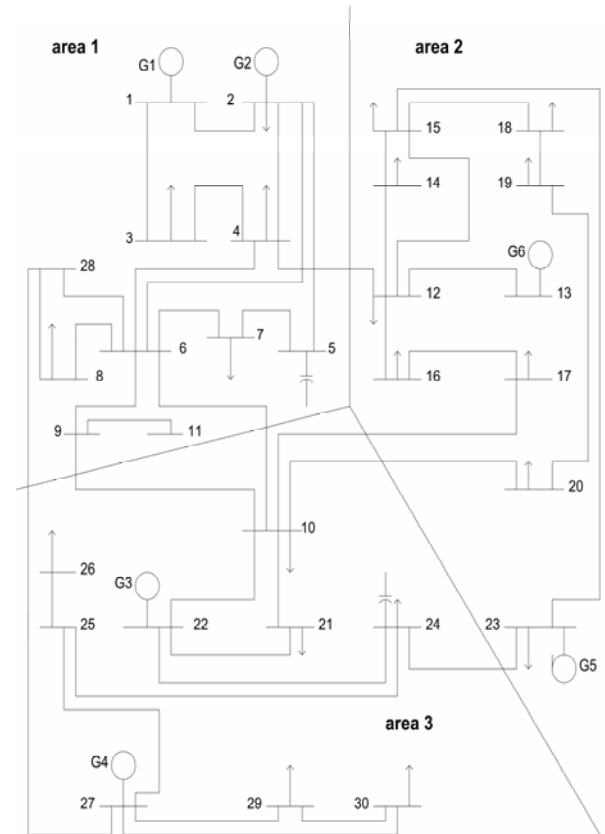


Fig. 2. Single line diagram of IEEE 30 bus system.

**Table 1: Test results of bilateral transaction from bus 2(area 1) to bus 21(area 3) of the IEEE 30 bus test system**

Objective function		Without TCSC	With TCSC	TCSC setting (p.u.)	Location of TCSC	Limit conditions
<b>Max. TTC &amp; min. loss (Case 1A)</b>	<b>TTC (MW)</b>	<b>26.50</b>	<b>32.50</b>	<b>-0.3360</b>	<b>Line 28 -27</b>	$Q_{G3}$
	$P_{loss}$ (MW)	<b>3.60</b>	<b>3.58</b>			
	$Q_{loss}$ (MVAR)	12.66	12.83			
<b>Max. only TTC (Case 1B)</b>	<b>TTC</b>	<b>26.50</b>	<b>33.00</b>	<b>-0.3361</b>	<b>Line 28 -27</b>	$Q_{G3}$
	$P_{loss}$	3.59	3.61			
	$Q_{loss}$	12.66	12.93			
<b>Min. only loss (Case1C)</b>	<b>TTC</b>	17.50	17.50	<b>-0.3360</b>	<b>Line 28 -27</b>	$Q_{G3}$
	$P_{loss}$	<b>2.99</b>	<b>2.84</b>			
	$Q_{loss}$	10.74	10.30			

**Table 2: Test results of Multilateral transaction from area 3 to area 2 of the IEEE 30 bus test system**

Objective function		Without TCSC	With TCSC	TCSC setting (p.u.)	Location of TCSC	Limit conditions
<b>Max. TTC &amp; min. loss (Case 2A)</b>	<b>TTC(MW)</b>	<b>75.40</b>	<b>84.20</b>	<b>-0.1136</b>	<b>Line 12- 13</b>	$V_{19}$
	$P_{loss}$ (MW)	<b>3.09</b>	<b>3.39</b>			
	$Q_{loss}$ (MVAR)	11.12	10.53			
<b>Max. only TTC (Case 2B)</b>	<b>TTC</b>	<b>75.40</b>	<b>82.60</b>	<b>-0.1136</b>	<b>Line 12-13</b>	$V_{19}$
	$P_{loss}$	3.09	3.31			
	$Q_{loss}$	11.12	10.25			
<b>Min. only loss (Case 2C)</b>	<b>TTC</b>	53.00	53.00	<b>-0.3361</b>	<b>Line 28- 27</b>	$V_{19}$
	$P_{loss}$	<b>2.34</b>	<b>2.17</b>			
	$Q_{loss}$	8.71	8.15			

**Table 3: Test results of contingency analysis of multilateral transaction from area 3 to area 2 of the IEEE 30 bus test system**

Case	TTC(MW) without TCSC	TTC(MW) with TCSC	TCSC setting (p.u.)	Location of TCSC	Limit conditions
Normal (Case 3A)	75.40	84.20	-0.1136	Line 12-13	$V_{19}$
<b>Largest generator G6 outage in area 2 (Case 3B)</b>	<b>54.60</b>	<b>61.80</b>	<b>-0.2100</b>	<b>Line 4-12</b>	Line 15-23 loading
Tie-line 23-24 outage (Case 3C)	55.40	64.20	-0.1136	Line 12-13	Line 15- 23 loading
<b>Contingency TTC value</b>	<b>54.60</b>	<b>61.80</b>	-----		

Table 2 shows the test results of multilateral transaction from area 3 to area 2. The base case load at area 2 is 53 MW. As shown in case 2A, TTC value can be increased from 75.40 MW to 84.20 MW after placing TCSC. Optimal TCSC setting is -0.1136 p.u. and location is line 12-13. Lower voltage limit violation of bus no. 19 prevents further transaction.

In Case 2C,  $P_{loss}$  can be reduced from 2.34 MW to 2.17 MW after placing TCSC in the line 28-27 with -0.3361 p.u. setting.

Table 3 shows the test results of contingency analysis of multilateral transaction from area 3 to 2. Only the outage of largest generator G6 in area 2 and tripping of tie-line between bus 23-24 have been considered in the contingency analysis. The base case TTC (Case 3A) without TCSC is 75.40 MW. The outage of generator G6 (Case 3B) reduces contingency TTC without TCSC to 54.60 MW. So TTC value is decreased by 27.58% compared to that without contingency constraints. So it is revealed that contingency constraints significantly reduce the value of TTC. So market participants should submit their bids after considering contingency constraints. In Case 3B, contingency TTC with TCSC is 61.80 MW which is 13.18% higher than contingency TTC without TCSC. So optimally placed TCSC can increase TTC under contingency condition also. Case 3B is the most severe contingency among Case 3B and Case 3C. So the feasible contingency TTC value with TCSC is 61.80 MW. Fig 3 shows that PSO converges in between 25 to 35 iterations for 20 independent simulations.

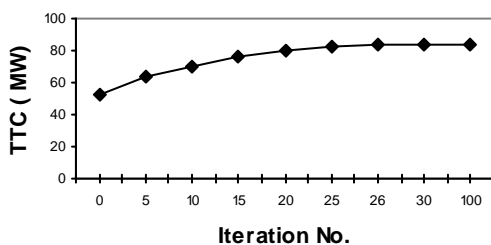


Fig. 3 Convergence characteristic of PSO

## 8. CONCLUSIONS

This paper has proposed PSO based algorithm to find optimal location and setting of TCSC for maximizing TTC and minimizing total real power losses of the competitive electricity markets having bilateral and multilateral transactions. Simulations were performed on IEEE 30 bus system. Test results indicate that optimally placed TCSC by PSO could significantly increase TTC, reduce real power losses and reactive power losses under normal and contingency conditions. In addition, PSO exhibits robust convergence characteristic so it can be used to effectively calculate TTC.

## 9. REFERENCES

- [1] Transmission Transfer Capability Task Force, North American Reliability Council (NERC), Available Transfer Capability Definitions and Determination, Princeton, New Jersey, 1996.
- [2] N.G. Hingorani, L. Gyugyi, Understanding FACTS Concepts and Technology of Flexible AC Transmission Systems, IEEE press, 2000, ISBN-0-7803-3455-8.
- [3] X. Yu, C. Singh, S. Jakovljevic, D. Ristanovic, G. Huang, Total transfer capability considering FACTS and security constraints, in: IEEE Conference (0-7803-8110-6/03/\$17.00), 2003.
- [4] G.C. Ejebe, J. Tong, J.G. Waight, J.G. Frame, X. Wang, W.F. Tinney, available transfer capability calculations, IEEE Trans. Power Syst., 13 (4) (1998) 1521-1527.
- [5] M.H. Gravener, C. Nwankpa, available transfer capability and first order sensitivity, IEEE Trans. Power Syst., 14(2) (1999) 512-518.
- [6] K.S. Verma, S.N. Singh, H.O. Gupta, FACTS device location for enhancement of total transfer capability, in: IEEE Power Engineering Society Winter Meeting, vol. 2, Feb. 2001, pp. 522-527.
- [7] Ying Xiao, Y.H. Song, Chen-Ching Liu, Y.Z. Sun, Available transfer capability enhancement using FACTS devices, IEEE Trans. Power Syst. 18 (1) (2003) 305-312.
- [8] M. Shaaban, W. Li, Z. Yen, Y. Ni, F. Wu, Calculation of total transfer capability incorporating the effect of reactive power, Electr. Power Syst. Res. 64 (2003) 181-188.
- [9] Weixing Li, Peng Wang, Zhizhong Guo, Determination of optimal total transfer capability using a probabilistic approach, IEEE Trans. Power Syst. 21 (2) (2006) 862-868.
- [10] Peerapol Jirapong, Weerakorn Ongsakul, Optimal placement of multi-type FACTS devices for total transfer capability enhancement using hybrid evolutionary algorithm, Electr. Power Components and Syst. 35 (2007) 981-1005.
- [11] M. Rashidinejad, H. Farahmand, M. Fotuhi-Firuzabad, A.A. Gharaveisi, ATC enhancement using TCSC via artificial intelligent techniques, Electr. Power Syst. Res. 78 (2008) 11-20.
- [12] J. Kennedy, R. Eberhart, Particle swarm optimization, in: Proceedings of the IEEE International Conference on Neural Networks, 1995, pp. 1942-1948.
- [13] J.B. Park, K.S. Lee, J.R. Shin, K.Y. Lee, A particle swarm optimization for economic dispatch with nonsmooth cost functions, IEEE Trans. Power Syst. 20 (1) (2005) 34-42.
- [14] B. Zhao, C.X. Guo, Y.J. Cao, A multiagent-based particle swarm optimization approach for optimal reactive power dispatch, IEEE Trans. Power Syst. 20 (2) (2005) 1070-1078.
- [15] S. Gerbex, R. Cherkaoui, A.J. Germond, Optimal location of multi-type FACTS devices in a power system by means of Genetic algorithms, IEEE Trans. Power Syst. 16 (3) (2001) 537-544.
- [16] R.D. Zimmerman, C.E. Murillo-Sanchez, MATPOWER, a Matlab power system simulation package, Version 3.2, 2007.