Mitigation of Congestion in Deregulated Electrical Power Systems using Particle Swarm Optimization

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Abstract: With the enhanced demand for electricity, the structure, operation, management, and ownership of electrical power system has been changed due to technical, financial, and ideological reasons. Recent trend involves augmentation of power systems in terms of geographical area, assets additions, and penetration of new technologies in generation, transmission, and distribution sectors. The congestion occurs when the generation and consumption of electric power causes the transmission system to operate beyond transfer limits. Flexible alternative current transmission system (FACTS) devices can be used to reduce the flows in heavily loaded lines, resulting in low power loss and improved stability of the system. Thyristor-controlled series compensator (TCSC) is an emerging FACTS device designated to achieve this objective. The conventional methods in solving optimization problems in power systems suffer from several limitations due to necessities of derivative existence, providing suboptimal solutions, etc. In this paper, PSO based algorithm has been suggested for minimizing active power rescheduling cost and reactive power rescheduling cost of generators to alleviate congestion in IEEE 30-bus system. The sensitivity parameters are used in comparing the alternative locations available for generation capacity and percentage of congestion. The simulation studies proved the efficiency of the proposed approach to minimize congestion by optimal placement of TCSC to minimize the losses and to improve the power transfer in a power system network.

Index Terms **- Flexible A.C. Transmission System (FACTS), Thyristor Controlled Series Compensator (TCSC), Total Transfer Capability (TTC), Particle Swarm optimization (PSO), Congestion Management**

I. INTRODUCTION

Congestion is defined as the overloading of one or more transmission lines and/or transformers in the power system. In the deregulated electricity market, congestion occurs when the transmission system is unable to accommodate all of their desired transactions due to violation of MVA limits of transmission lines. In such a market, most of the time, the transmission lines operate near their stability limits, as all market players try to maximize their profits from various transactions by fully utilizing transmission systems. Congestion may also occur due to various factors, such as lack of coordination between and transmission companies (TRANSCOs), contingency like generator/line outage, sudden change in load demand, and failure of various equipment. Congestion may lead to a rise in cost of electricity, tripping of overloaded lines, and consequential tripping of other healthy lines. Congestion should be relieved to maintain power system stability and security; otherwise, it may result in system blackout with heavy loss of revenue. So, congestion management is given the highest priority, followed by cost recovery, etc., by the Federal Energy Regulatory Commission (FERC) [1] and many other utilities.

The present trend of congestion management is to use pricing tools, in the form of nodal and zonal pricing [2]. Despite these tools, congestion still exists and the level of congestion is increasing, alarmingly [3,4]. Due to economic, environmental and political reasons it is not preferable to build new transmission lines. Therefore, there exist an opportunity for technological means to remove or to reduce the transmission bottlenecks. 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 [5]. FACTS are the power electronics based converter-inverter circuits which can enhance TTC, voltage stability, load ability, security etc. and can reduce losses, production cost of generation, can remove congestion and fulfill transaction requirement rapidly and efficiently. It is necessary to "optimally" locate FACTS devices in order to obtain their full benefits [6]. Various classical and artificial intelligence methods have been suggested to optimally locate FACTS devices with different kinds of objective functions. So, it is revealed that most of the OPF problems are non-linear and non-convex. With the inclusion of FACTS control variables, they become even more nonlinear because they change the size of bus admittance matrix and dimension of the problem. Conventional classical optimization methods like gradient method, lamda iteration, linear programming etc. rely on the convexity assumption of objective function. They fail to capture discontinuities of objective function and may get trapped into local minima or diverge at all. Choice of initial starting point also affects the quality of solution. Also, they could find only single optimized solution in a single simulation run. Thus, to find global optimum solution is a challenging task in optimization problem incorporating FACTS devices.

To solve such problem, an artificial intelligent method called Particle Swarm Optimization may be used as it is a fast method and it provides global or near global solution [7]. PSO has shown its superiority over other classical and AI methods with respect to execution time and global solution in solving economic dispatch problem [8], optimal reactive power dispatch problem [9]and congestion management [10] Transmission service pricing is also an important issue of deregulated market. Out of many suggested pricing methods, Locational Marginal Pricing (LMP) method is popular because it considers all system constraints and losses. As PSO cannot provide Lagrange multipliers which are required for finding LMP, an interior point method is used to calculate LMP. But choice of initial starting points greatly affects the quality of solution of interior point method.

Congestion management is the highest priority problem that the system operator has to solve in his routine activity. Several congestion management schemes suitable for different electricity market structure have been reported in literature survey.

In optimal power flow based method, congestion has been managed by either rescheduling of active power output of generators or curtailing the loads [[10], [12], [13],[14] and [15]]. The optimal placement of FACTS controller [16] using sensitivity based approach [[15] and [17]] and their role in the congestion management have been also reported. [18] has addressed the role of reactive power in congestion management. From literature survey, it is observed that very few papers have addressed the role of reactive power of the generators in congestion management. Reactive power plays an important role in supporting real power transfer and maintaining voltage stability of the bus bars in the post-rescheduling state. So, reactive power rescheduling of generators should be incorporated in OPF problem. Secondly, all generators do not take part in congestion management. Only a few generators, based upon their active power sensitivities to the congested line have been selected for managing congestion [10]. So, there is a need to develop a method through which reactive power sensitivity factors of the generators to the congested lines may be found out and from those sensitivity factors the number of participating generators whose reactive power have to be rescheduled could be found out.

II. MODELING OF TCSC

Thyristor Controlled Series Capacitor (TCSC) is a series type fact controller. Fig.1 the TCSC has been represented by a variable capacitive/inductive reactance inserted in series with the transmission line. So the reactance of the transmission line is adjusted by TCSC directly.

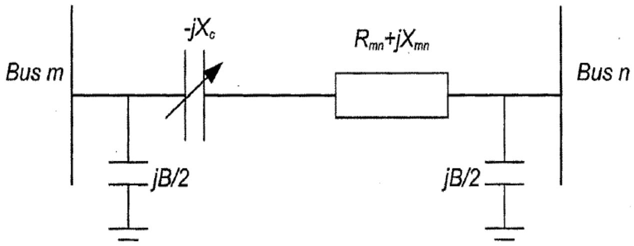

Fig.1: Equivalent circuit of a transmission line after placing TCSC

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 follows:
in the conversion of rotating reference into stationary reference frame are as follows:

$$X_{new} = X_{mn} - X_c \tag{1}$$

The modified power flow equations of the transmission due to insertion of TCSC can be written as follows:

$$P_{mn} = V_m^2 G_{mn} - V_m V_n (G_{mn} Cos\delta_{mn} + B_{mn} Sin\,\delta_{mn}) \tag{2}$$

$$Q_{mn} = -V_m^2 (B_{mn} + B/2) + V_m V_n (G_{mn} Sin\delta_{mn} - B_{mn} Cos\,\delta_{mn}) \tag{3}$$

$$P_{nm} = V_n^2 G_{nm} - V_m V_n (G_{nm} Cos\delta_{nm} - B_{nm} Sin\delta_{nm}) \tag{4}$$

$$Q_{nm} = -V_n^2 (B_{nm} + B/2) + V_m V_n (G_{nm} Sin\delta_{nm} + B_{nm} Cos\delta_{nm}) \tag{5}$$

Where,

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

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

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

G_{mn} : Resultant conductance of the line after placing TCSC

B_{mn} : Resultant susceptance of the line after placing TCSC

R_{mn} : Resistance of the line

If TCSC is connected between bus m and bus n, then only following entries of bus admittance matrix (y_{bus}) will change, i.e. mm, mn, nm and nn entries will change. Let us consider a simple example. Suppose system consists of 5 buses and TCSC is connected between bus 2 and bus 3. If TCSC offers a change in net line admittance by Δy , the admittance matrix will become as follows:

$$y_{bus} = \begin{bmatrix} y_{11} & y_{12} & y_{13} & y_{14} & y_{15} \\ y_{21} & (y_{22}+\Delta y) & (y_{23}-\Delta y) & y_{24} & y_{25} \\ y_{31} & (y_{32}-\Delta y) & (y_{33}+\Delta y) & y_{34} & y_{35} \\ y_{41} & y_{42} & y_{43} & y_{44} & y_{45} \\ y_{51} & y_{52} & y_{53} & y_{54} & y_{55} \end{bmatrix} \quad (6)$$

III. Optimal Power Flow Problem Formulation

The active and reactive power redispatching cost of generators for congestion management in a pool model is formulated as a nonlinear OPF problem and has been solved by PSO method.

$$\therefore \quad Min.\left\{ \sum_{g}^{N_g} C_{Pg}(\Delta P_g)\Delta P_g + \sum_{g}^{N_g} C_{Qg}(\Delta Q_g)\Delta Q_g + k_1 L_{\max} + k_2 \sum_{i=1}^{N_d} |1 - V_i| + PF \right\} \quad (7)$$

This OPF is subjected to various equality constraints (power flow balance equations)

$$\left\{ P_{Gm} - P_{Dm} - \sum_{n=1}^{N_b} |V_m||V_n||Y_{mn}| Cos(\delta_m - \delta_n - \theta_{mn}) = 0 \right\}, For\ each\ PV\ bus\ except\ slack\ bus \quad (8)$$

$$\left\{ Q_{Gm} - Q_{Dm} - \sum_{n=1}^{N_b} |V_m||V_n||Y_{mn}| \mathrm{Sin}(\delta_m - \delta_n - \theta_{mn}) = 0 \right\}, For\ each\ PQ\ bus \quad (9)$$

Various inequality constraints (operating constraints

$$P_g - P_g^{min} = \Delta P_g^{min} \le P_g \le \Delta P_g^{max} = P_g^{max} - P_g, \qquad g \in N_g \quad (10)$$

$$Q_g - Q_g^{min} = \Delta Q_g^{min} \le \Delta Q_g \le \Delta Q_g^{max} = Q_g^{max} - Q_g, \qquad g \in N_g \quad (11)$$

$$|S_k| \le S_k^{max}, \quad k \in N_l \quad (12)$$

$$V_i - V_i^{min} = \Delta V_i^{min} \le \Delta V_i \le \Delta V_i^{max} = V_i^{max} - V_i; \quad i \in N_b \quad (13)$$

The effect of generator sensitivity factors is considered as an inequality constraint as follows:

$$\left\{ \left\{ (\sum_{g}^{N_g} GS_{Pgn}^{k} \times \Delta P_g) + P_{ij} \right\}^2 + \left\{ (\sum_{g}^{N_g} GS_{Qgn}^{k} \times \Delta Q_g) + Q_{ij} \right\}^2 \right\} \le (S_{ij}^{max})^2; i, j \in N_l \quad (14)$$

Where,

C_{pg} : Cost of the active power rescheduling corresponding to the incremental/decremental price bids submitted by generator-*g* participating in congestion management. These are the prices at which the generators are willing to adjust their real power outputs.

ΔP_g : Active power adjustment of the generator-*g*

ΔQ_g : Active power adjustment of the generator-*g*

$C_{Qg}(\Delta Q_g)$: Cost of the reactive power rescheduling (opportunity cost) of generator-*g* participating in congestion management. It is expressed as follows:

$$C_{Qg}(\Delta Q_g) = \left\{ C_g^P(S_{G\,max}) - C_g^P(\sqrt{S_{Gmax}^2 - \Delta Q_g^2}) \right\} \times \psi \quad (15)$$

Where,

$$C_g^P(\Delta\Delta P_{gn}) = a_n(\Delta\Delta P_{gn}^2) + b_n(\Delta\Delta P_{gn}) + c_n \quad (16)$$

where,

a_n, b_n and c_n : Predetermined cost coefficients of g^{th} generator

$S_{G\,max}$: The maximum apparent power limit of generator- *g*, k_1 : A constant=10,000

ψ is the profit rate of active power generation taken between 5 and 10%. Here, it is taken as 7.5%.

L_{max} : Maximum value of voltage stability indicator (L-index). L index gives a scalar value to each load bus and it lies in the range from zero (no load case) to unity (voltage collapse point)

k_2 : A constant=1,000

Voltage profile improvement criterion (i.e summation of load bus voltage deviations from 1.0 pu) is given as follows:

$$\sum_{i=1}^{N_d} |1 - V_i| \quad (17)$$

PF: Penalty function

P_{Gi}, Q_{Gi} : Active and reactive power generation at bus *i*

P_{Di}, Q_{Di} : Active and reactive power demand at bus *i*

$|V_i|\angle\delta_i$: Complex voltage at bus *i*

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

P_g^{min}, P_g^{max} : Minimum and maximum active power generation limits of generator *g*, respectively

$\Delta P_g^{min}, \Delta P_g^{max}$: Minimum and maximum limits of the change in generator active power outputs, respectively

Q_g^{min}, Q_g^{max} : Reactive power generation limits of generator *g*.

$\Delta Q_g^{min}, \Delta Q_g^{max}$: Minimum and maximum limits of the change in generator reactive power outputs, respectively.

S_k : power flow in the transmission line *k* caused by all contracts requesting the transmission service

$S_k^{max} = S_{ij}^{max}$: MVA flow limit of k^{th} transmission line connected between bus-*i* and bus-j

V_i^{min}, V_i^{max} : Minimum and maximum voltage magnitude limits at bus *i* respectively

$\Delta V_i^{min}, \Delta V_i^{max}$: Minimum and maximum limits of the change in bus voltage magnitude at bus *i* respectively

L_{index}^i : Voltage stability indicator (L-index) of bus *i*

N_l : Total number of transmission lines, N_b : Total number of buses, N_g : Total number of generator buses,

N_d : Total number of load buses

P_{ij}, Q_{ij} : Original active power and reactive power flow in line- *k* (between bus-'i and *bus-j)* caused by all transactions requesting the transmission service.

Square penalty function is used to handle inequality constraints such as active power output of slack bus generator, reactive power output of generator buses, voltage magnitude of all buses and transmission line MVA limits as shown in equations 34 and 35

$$PF = k_3 \times f(P_1) + k_4 \times \sum_{i=1}^{N_g} f(Q_{gi}) + k_5 \times \sum_{i=1}^{N_b} f(V_i) + k_6 \times \sum_{k=1}^{N_l} f(S_k)$$

(18)

$$f(x) = \begin{cases} 0, \ if \quad x^{\min} \le x \le x^{\max} \\ (x - x^{\max})^2, if \ x > x^{\max} \\ (x^{\min} - x)^2, if \ x < x^{\max} \end{cases} \quad (19)$$

where k_3, k_4, k_5 and k_6 : The value of each penalty coefficient is equal to 1000.

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

IV. Particle Swarm Optimization (PSO) Algorithm

Particle Swarm Optimization (PSO) is a fast, simple and efficient population-based optimization method which was proposed by Eberhart and Kennedy [8] in the year 1995. It is an exciting new methodology in evolutionary computation and a population based optimization tool like Genetic algorithm. It has been motivated by the behavior of organisms such as fish schooling and bird flocking. It requires less computation time and less memory because of its inherent simplicity. The basic assumption behind the PSO algorithm is that birds find food by flocking and not individually. This leads to the assumption that information is owned jointly in the flocking. The swarm initially has a population of random solutions. Each potential solution, called a particle (agent), is given a random velocity and is flown through the problem space. All particles have memory and each particle keeps track of its previous best position (P_{best}) and the corresponding fitness value. The swarm has another value called (g_{best}), which is the best value of all particles P_{best}. It has been found to be extremely effective in solving a wide range of engineering problems and solves them very quickly.

In a PSO, population of particles exists in the n-dimensional search space. Each particle has certain amount of knowledge and will move about the search space on the basis of this knowledge. The particle has some inertia attributed to it and hence will continue to have a component of motion in the direction it is moving. The particle knows its location in the search space and will encounter with the best solution. The particle will then modify its direction such that it has additional components towards its own best position (P_{best}) and towards the overall best position (g_{best}). 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:

$$v_i^{k+1} = w \times v_i^k + c_1 \times r_1 \times (P_{besti} - x_i^k) + c_2 \times r_2 \times (g_{best} - x_i^k) \quad (20)$$

$$x_i^{k+1} = x_i^k + \chi \times v_i^{k+1} \quad (21)$$

where,

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

w: Inertia weight of the particle

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

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

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

P_{besti}: The best position of 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 kth iteration

χ : Constriction factor. It may help insure convergence. Its low value facilitates fast convergence and little exploration while high value results in slow convergence and much exploration.

Constant c_1 is called a self-confidence range, c_2 is called swarm range. Both coefficients pull particle towards P_{best} and g_{best} positions. Low values of acceleration coefficients allow particles to roam far from the target regions, before being tugged back. On the other hand, high values result in abrupt movement towards or past the target regions. The term $(c_1 \times r_1 \times (P_{besti} - x_i^k)))$ is called particle "Memory influence" or "Cognition part" which represents the private thinking of the particle itself and the term $(c_2 \times r_2 \times (g_{besti} - x_i^k)))$ is called "Swarm influence" or the "Social part" which represents the collaboration among the particles.

In PSO algorithm, the value of maximum allowed particle velocity v_{max} ,determines the resolution with which regions are to be searched between the present position and the target position. If v_{max} is too high, particles may fly past good solutions. If v_{max} is too small, particles may not explore sufficiently beyond local solutions. Thus, the system parameter v_{max} has the beneficial effect of preventing explosion and scales the exploration of the particle search. The choice of a value for v_{max} is generally set to 10-20% of the range of the each variable. Suitable selection of inertia weight w provides good balance between global and local explorations. It is set according the following equation.

$$w = w_{max} - \frac{w_{max} - w_{min}}{iter_{max}} \times iter \quad (22)$$

where, w_{max} is the value of inertia weight at the beginning of iterations, w_{min} is the value of inertia weight at the end of iterations, iter is the current iteration number and $iter_{max}$ is the maximum number of iterations.

Fig.2. shows the graphical representation of PSO method . S^k is the current position of the i^{th} particle in k^{th} iteration. $v^{k+1}$is the velocity of the i^{th} particle in $(k + l)^{th}$ iteration. This velocity is obtained by using information of V^k, P_{best} and g_{best} particles. Finally, new position $S^{(K+1)}$ of the i^{th} particle in $(k+l)^{th}$ iteration is obtained using S^k and V^{K+1}

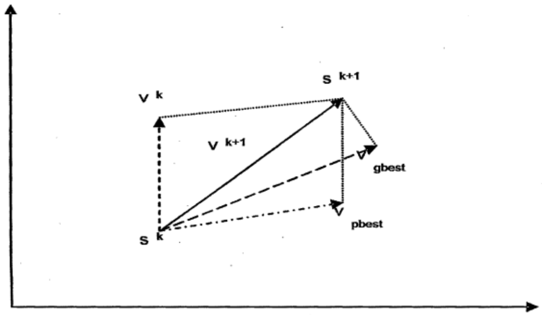

Fig 2: Graphical representation of PSO

PSO based algorithm for Congestion Management:

1. Run Newton-Raphson load flow to identify the overloaded lines.
2. Find out the sensitivity of all generators to the congested lines, i.e. find active power generator sensitivity factors and reactive power generator sensitivity factors of all generators corresponding to each congested line.
3. Based upon obtained sensitivity factors, identify the generators which will take part in managing congestion.
4. In PSO, initialize particles with values of position and velocity. Each particle is made of continuous variables. The values of these variables are the amount of active power rescheduling ($\Delta P_{gNG,i}$) and amount of generator voltage rescheduling ($\Delta V_{gNG,i}$) required by generators to manage congestion. As the reactive power output of a generator is a function of generator voltage, any rescheduling in generator voltage will reschedule its reactive power. These variables are generated randomly within their permissible minimum and maximum limits.
5. Run Newton-Raphson load flow to get line flows, active power rescheduling, reactive power rescheduling, line losses and voltage magnitude of all buses.
6. Find constraint violation and calculate penalty function of each particle using equation 18
7. Calculate the fitness function of each particle using equation 7
8. Find out the “global best” particle having minimum value of fitness function in the whole population and “personal best” of all particles.
9. Generate new population using equations 20 and 21
10. Go to step 5 until convergence criterion is satisfied.
11. Stop the simulation.

$\Delta P_{g1,i}$, $\Delta P_{gNG,i}$: Active power rescheduling of participating generators of i^{th} particle

$\Delta V_{g1,i}$, $\Delta V_{gNG,i}$: Voltage rescheduling (reactive power rescheduling) of participating generators of i^{th} particle.

If there are total *i* number of particles and if each particle consists of *j* number of control variables, then dimension of a population becomes *i* * *j*.

V. Results And Discussion:

Before 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 shown in Fig.3.

5.1 Maximization of TTC & Minimization of active power losses

In this work, PSO based algorithm is proposed 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.

The IEEE 30-bus system has been used to demonstrate suitability of the proposed algorithm. The bus, line and generator data is taken from MATPOWER . It consists of 6 generators and 41 transmission lines. 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) Maximize only TTC (ii) Minimize only active power loss. (iii) Simultaneously maximize TTC and minimize active power loss (Ploss), , have been considered.

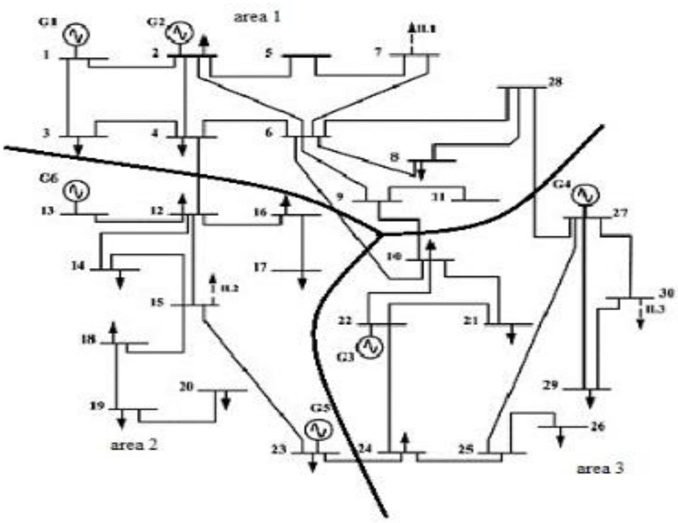

Fig: 3 IEEE single line 30-bus System diagram

Table 1 shows the operating conditions tested for simulation studies. Table 2 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.

Table 1: Operating Conditions

Case	**Condition**
Case A	Maximization of TTC Only
Case B	Minimization of active power loss only
Case C	Simultaneous maximization of TTC and minimization of active power loss

Table 2: Test results of bilateral transactions from bus 2 (area1) to bus 21 (area 3) of the IEEE 30 bus test systems

	Case 1A		Case 1B		Case 1C	
	TTC (MW)	P_{loss} (MW)	Q_{loss} (MVAR)	TTC (MW)	P_{loss} (MW)	Q_{loss} (MVAR)
Without TCSC	26.50	3.59	12.66	17.50	2.99	10.74
With TCSC	33.00	3.61	12.93	17.50	2.84	10.30

Case 1C 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 1B shows the results of minimization of loss only.

Table 3: Test results of multilateral transaction from area3 to area 2 bus of IEEE 30- bus test system

	Case 2A		Case 2B		Case 2C	
	TTC (MW)	P_{loss} (MW)	Q_{loss} (MVAR)	TTC (MW)	P_{loss} (MW)	Q_{loss} (MVAR)
Without TCSC	75.40	3.09	11.12	53.00	2.34	8.71
With TCSC	85.40	3.47	11.03	53.00	2.17	8.15

Base case TTC is 17.50 MW. Ploss 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 (Qloss). It reduces Qloss from 10.74 MVAR to 10.30MVAR.Table 3 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 2B, Ploss 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. In addition, optimally place TCSC has significantly reduced reactive power losses in cases 2A, 2B and 2C.

Table 4: Test results of contingency analysis of multilateral from area 3 to area 2 of IEEE 30-Bus test system

	Normal (Case 3A)	Largest generator G_6outage in area 2 (Case 3B)	The Line 23-24 outage (Case 3C)	Contingency TTC Value
Without TCSC	75.40	54.60	55.40	54.60
With TCSC	84.20	61.80	64.20	61.80

Table 4 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.

To facilitate the deregulated electricity market operation, control and trading, sufficient transmission capability should be provided to satisfy increasing demand of power transactions reliably. The contribution of this chapter can be summarized as follows, This work 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 which consist of bilateral and multilateral transactions. 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.PSO exhibits robust convergence characteristic so it could be used to effectively calculate TTC and PSO obtains global solution with in 40 iterations, so the proposed method can be used to evaluate TTC in on-line TTC measurement system

5.2 Congestion Management

The purpose of paper work is to suggest an efficient method for selecting number of participating generators and optimum rescheduling of active and reactive power output of generators for managing congestion at minimum rescheduling cost. Generally, all generators do not have the same effect (sensitivity) on the power flow of a congested line. So in practical situation, only a few generators take part in removing congestion. So firstly, active power and reactive power sensitivity factors of generators to the congested line are found out. The number of participating generators is selected from sensitivity factors. Secondly, active and reactive power rescheduling of participating generators are optimally done in such a way that the total active and reactive power rescheduling costs get minimized. Sometimes, congestion alleviation results into larger voltage deviations or very low voltage profile at load buses, which may invite voltage collapse. So, voltages of generators have been rescheduled to keep load bus voltages within permissible limits. The PSO based algorithm has been tested on IEEE 30-bus test system .Obtained results have been compared with those of other published papers.

The IEEE 30-bus system has-been used to test effectiveness of the proposed algorithm and obtained results have been compared with those of [10] and [19]. It consists of 6 generator buses, 24 load buses and 41 transmission lines. Slack bus generator is assigned number 1. Remaining generators are assigned numbers 2,3,4,5 and 6 respectively. Load buses are numbered from 7 to 30. Here, two lines i.e. line no. 1 (between buses 1 and 2) and line no. 6(between buses 2 and 9) are found to be congested. Details of power flow of congested lines are given in Table 5. The values generators sensitivity factors computed for the lines 1-2 and 2-9 are given in Table 6.

Table 5: Details of power flow of congested lines IEEE 30-bus system

Congested line	Power flow(MW)	Line flow limit(MW)
1-2	170.30	130
2-9	68.75	65

Table 6: Generator sensitivity factors congested lines of IEEE 30-bus system

Congested lines		Generator no.					
		1	2	3	4	5	6
Line 1 (bus 1-2)	GS^1_{Pgn}	-0.000	-0.077	-0.127	-0.105	+0.17	-0.420
	GS^1_{Qgn}	-0.779	-0.867	-0.744	-0.788	-0.761	-0.775
Line 6 (bus 2-9)	GS^6_{Pgn}	-0.000	-0.014	-0.029	-0.029	+0.326	-0.116
	GS^6_{Qgn}	-0.356	-0.351	-0.327	-0.368	-0.354	-0.357

A negative value of sensitivity factor of a generator indicates that an increase in generation for that generator decreases the power flow in the congested line. Whereas, a positive sensitivity factor of a generator indicates that an increase in generation increases power flow in the congested line. From the table 6, it is seen that the generators 1,2,3,4 and 6 have negative sensitivity factors, while the generator 5 has positive sensitivity factor. So, only generators 1,2,3,4 and 6 would take part in removing congestion from the congested lines. The generator 5 does not take part in removing congestion. Now, PSO is applied to optimally reschedule the output powers of generators to manage congestion. It is to be noted that the sensitivity factors obtained are with respect to the slack bus which is considered as the reference bus and change in phase angle ($\Delta\delta$ = 0) of slack bus is zero during the load flow execution. So, the active power generator sensitivity factors of a slack bus generator is zero for both congested lines. But, reactive power generator sensitivity factors of a slack bus generator may not be zero for congested lines, because during load flow execution, a non-zero voltage is specified at a slack bus.

It can be seen that cost of active power rescheduling and total active power rescheduling obtained by the proposed method is lesser than those of [10] and [19]. Also, it is interesting to note that the total rescheduling cost (active power rescheduling cost +reactive power rescheduling cost) obtained by the proposed method is still lesser than those of [10] and [19]. So, it is preferable to reschedule reactive power output of generators for removing congestion. Overloading of both congested lines was sufficiently removed by the proposed method. Also, obtained active power losses by the proposed method were lesser than that of [10].

Furthermore, Reactive power rescheduling helped in improving voltage stability of the load buses and it took the system far away from voltage collapse point. It is clear from Fig. 4 that voltage stability has increased because L-index values of load buses have considerably decreased in post-rescheduling state.

Reactive power rescheduling also decreased deviation in voltage of load buses from the rated 1.0 pu. value. Thus, it improved voltage profile of the load buses. The results are given in Table 7

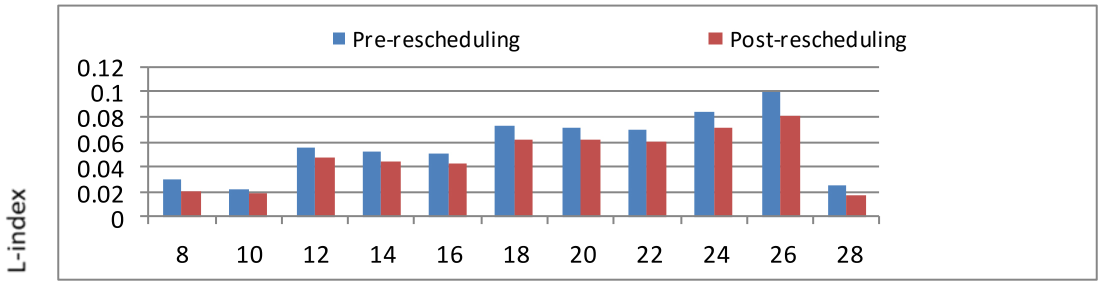

Fig.4: L-index values of some load buses before and rescheduling for IEEE 30 bus system

Table 7: Voltage stability and voltage deviation indicators in pre-rescheduling and post scheduling states of 30 bus system

	Pre-rescheduling	Post-rescheduling
L_{MAX}	0.1007	0.0815
$\sum$ Voltage deviation	1.205	0.659

Table 8: Statistical results of rescheduling costs for IEEE 30-bus system

Rescheduling cost($/day)	Worst cost	Best cost	Average cost
Active power rescheduling cost	41,000	28,130	31,286
Reactive power rescheduling cost	8,200	6,051	7,641

Table 9: Comparison of results obtained by PSO for congestion management of IEEE 30 bus system

		Proposed method	Results reported in[10]	Results reported in[19]
Cost of active power rescheduling ($/day)		31,286	50,466	50,700
Cost of reactive power rescheduling ($/day)		7,641	Not reported	Not reported
Resultant power flow(MW)	Line 1	128.16	129	130
	Line 6	63.24	60	60
Active power rescheduling (MW)	ΔP_1	-43.20	-59	-58
	ΔP_2	+16.67	+19.9	+20.5
	ΔP_3	+10.06	+13	+14.5
	ΔP_4	+14.20	+6	
	ΔP_5	Not participated	+6.5	+9.2
	ΔP_6	+2.75	+7	…
Total active power rescheduling(MW)		86.88	111.4	110.2
Reactive power Rescheduling(MVAR)	ΔQ_1	-29.99	Not reported	Not reported
	ΔQ_2	+80.00		
	ΔQ_3	+00.94		
	ΔQ_4	00.00		
	ΔQ_5	Not participated		
	ΔQ_6	-31.42		
Total reactive power rescheduling (MVAR)		142.35		
Total active power losses(MW)		11.39	15	Not reported

Instead of using all generators for managing congestion, only a few generators may be used to manage congestion and the generators which take part in congestion management may be selected based upon their sensitivities to the congested lines. Reactive power rescheduling helped in improving voltage profile of the load buses and it enhanced voltage stability of the system in the post-rescheduling state. Losses obtained by the proposed method were significantly lower than those of other reported methods

Hence, the proposed algorithm improved performance of the system in the post-rescheduling state. Thus, experiment showed encouraging results, suggesting that the proposed PSO based approach was capable of efficiently determining higher quality solutions addressing congestion management.

VI. CONCLUSION

As a consequence of deregulation of electrical power systems, there is growing interest about the transfer capabilities of transmission lines with increased wheeling transactions. But due to the economical, environmental and political reasons it is very difficult to build new transmission lines. So there is an interest in optimal utilization of the existing transmission systems by installing new FACTS device like TCSC. TCSC is popularly used FACTs device which offers many advantages. But due to many reasons, it is very important to optimally locate it to obtain its full benefits. This paper has mainly addressed the issues of optimal placement and setting of TCSC considering different types of objectives, such as maximization of Total Transfer Capability (TTC), minimization of total real power losses,. Lastly, the most fundamental and highest priority transmission management problem *i.e.*, congestion management has been solved. The robustness of the proposed algorithm has been tested and validated with TCSC on IEEE 30-bus power systems..

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