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Congestion Management in Deregulated Power System Using Heuristic Search Algorithms Incorporating Wireless Technology

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Abstract The impact of restructuring in the field of communication sector has brought an evolutionary change in power sector too. This revolutionary idea has brought about competition in this sector with an aim of reduction in the electricity price. The competitive environment not only benefits the utilities and customers however it kindles some of the technical issues, typical one being the transmission congestion. It is considered to be tenacious since it admonish system security and may result in inflation of electricity prices effecting in feeble market condition. The explication to the dispute of congestion has been furnished in this paper. To minimize the congestion cost, an effective multi objective approach is proposed to endorse generator rescheduling and FACTS technology using a metaheurisitc optimization algorithm, symbiotic organic search algorithm. The choice of most sensitive generators to reschedule real and reactive power is realized using real power transmission congestion distribution factor. The proposed method has been tested on IEEE 14 bus system and IEEE 30 bus system.

Keywords Congestion management · Symbiotic organic search · Transmission congestion distribution factor · Newton–Raphson (NR)

1 Introduction

With the rise in mechanization, sophistication and enrichment of lifestyle, the obligation on the electrical power has enlarged. Due to hasty increase of load and deficiency of requisite resources, the dispute of power smashup and power outages occur. The power sector is

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amenable to elucidate this sprouting need for electrical power along with atoning the economical and security factors. The amendments passed in “The Electricity Act 2003”, pave the way for taking measures contributive to the development of power industry, concurring competition therein, mitigation of electricity tariff affirming transparent, efficient and environmental amiable policies. Consequently, the monopolistic power sector accomplished as vertically integrated utility (VIU) has been privatized and unbundled into generation, transmission and distribution companies [1]. Around the world the practice o privatization and restructuring of electric power markets has a large bang on the power systems. The participants being the buyers and sellers of electrical power play a major role and they make the power market more competitive. Henceforth, restructuring in electric power sector has inspired greater utilization of transmission lines. While the producers and consumers of electric power ought to sell and buy in extent that would antecedent the transmission lines to operate at or beyond at least one of the transfer limits, the system is said to be congested. Congestion in transmission lines result in forbidding the existence of new contracts, sequential blackouts, augmentation of electricity prices and moreover it enforce the system security and reliability. Thereupon a control strategy is very much indispensable to attenuate the transmission line congestion satisfying security limits in a merest time. Congestion management is such a strategy to alleviate congestion in the lines perhaps sustaining the system security. Independent system operator (ISO) is solely responsible to handle congestion for it is the most discerning and significant deed as it hazards the system security and has the liability to cause rise in electricity prices eventuating in sloppy power market. Essentially two congestion management techniques are being followed namely cost free means and non-cost free means. The former method utilizes FACTS devices, phase shifters, transformer taps and network reconfiguration to mitigate congestion whereas some of the rarer methods are generator rescheduling, prioritization and curtailment of loads. In VIU congestion was dealt by regulating the output power of the generator thus retaining system security. Nevertheless in deregulation congestion is associated with competition and surge in electricity prices. Many research works are being proposed in order to alleviate congestion and review on various congestion management methods are presented.

In [2], congestion is relieved using optimal power flow (OPF) based congestion algorithm to maximize the social welfare. In [3], a distinct locational marginal price (LMP) approach for placing series Facts devices in a deregulated power market to relieve congestion is discussed. The authors in [4] employ the loss sensitivity factor method to arbitrate the suitable location of TCSC whereas the PSO based real power flow performance sensitivity is proposed for the optimal location of TCSC in [5]. In [6], sensitivity based approach i.e. reduction of total system VAR power loss and real power flow performance index sensitivity indices is proposed to mitigate congestion. Application of Fuzzy technology in congestion management is identified in [7]. In [8], a multiobjective PSO is proposed to simultaneously minimize the congestion and generator scheduling cost. Authors in [9] employed firefly algorithm to solve multiobjective congestion problem incorporated with Interline Power Flow Controller (IPFC). In [10], the OPF problem is solved using hybrid Bacterial Foraging (BF) algorithm and Nelder-Mead (NM) method; the optimal location to place TCSC for congestion management is carried out with congestion rent contribution method. A GA based solution methodology is developed in [11], [12] and [13] for parameter setting and optimally locating FACTS device to relieve congestion. In [14], relative electrical distance based real power generation rescheduling is proposed satisfying the stability margins of the system. The authors in [15] proposed congestion management technique based on PSO with time varying acceleration coefficients by rescheduling the active power of the generators. Development of a novel algorithm to control the Facts and D-Facts devices connected in a n-bus system has accomplished in [16]. Furthermore, employing multiple TCSCs [17], UPFC, SVC, TPST has been realized for the very prospect. In [18], the conventional method to realize the location of TCSC in a competitive power market by trial and error method is discussed.

As discussed above many remedies are being carried out to solve this critical technical issue. This paper suggests a multi objective optimization approach to mitigate the congestion caused in the lines. The objectives being the (1) minimization of congestion cost (2) parameter setting, location and installation cost of TCSC and (3) minimization of losses incurred in the lines. A detailed comparison on the effectiveness of PSO and SOS algorithms on the proposed objective has been done.

2 Particle Swarm Optimization in Congestion Management

PSO is a stochastic optimization method executed by Kennedy et al. [19]. This method is meant for its clarity and faster rate of convergence [20]. The technique provides fair solution for non-convex and discontinuous optimization problems. Like other evolutionary algorithms, PSO as well is a population based optimization algorithm which replicates the emergent movement of swarm of birds flying in search of food. Each member in the search space is a particle and every particle moves throughout the search space searching for its global minimum (or maximum) called as gbest. While traversing, the velocity of the individual particle is adjusted at every instant and the particle is updated to its new position in consonance with its own experience and of its neighboring particles.

In the course of every generation, two values are updated for each particle viz. the best position or fitness value it has attained earlier called as the position best or pbest, $P_i = (p_{i1}, p_{i2}, \ldots, p_{in})$ and the best value attained by any other particle in the population called as global best or gbest, $Gi = (g_{b1}, g_{b2}, \ldots, g_{in})$. In a N-dimensional space, every particle is considered to be a solution whose prominent and subordinate degree are evaluated by computing its fitness value. The particles have the liability to hold memory of the best positions they have attained during the course of traverse in search space and share this information to the other particle. Considering N dimensional space, the particles are generated randomly and it posses two parameters (1) position of the particle $X_i = (X_{i1}, X_{i2}, \ldots, X_{in})$ and (2) velocity of the particle, $V_i = (V_{i1}, V_{i2}, \ldots, V_{in})$. Based on the information about its pbest and gbest values the particles update their positions and velocities using the following equation,

$$V_i^{k=1} = \omega * V_i^k + C_1 * \text{rand1} * \left(P_i^k - X_i^k\right) + C_2 * \text{rand2} * \left(gb^k - X_i^k\right) \tag{1}$$

$$X_i^{k+1} = X_i^k + V_i^{K+1} \tag{2}$$

where, ω represents inertia weight, rand 1 and rand 2 represents random values between 0 and 1, $C_1 = 2$ and $C_2 = 2$ called as acceleration constants, k represents the iteration number (Table 1).

The step by step process in PSO algorithm is summarized below,

1. Prepare the line data, bus data and all the relevant datas of the bus system to be considered along with the parameters of PSO.
2. Impose congestion in the bus system and run NR power flow for the given generation and load pattern.

Table 1 PSO parameters

Parameter	Value
Inertia	0.3
Damping ratio	0.95
Particle size	20
Max. iteration	20
C_1	2
C_2	2

3. Generate a random set of control variables using PSO procedure for instance incremental and decremental generation shift, TCSC parameters satisfying the limits. The values obtained are enforced in the system data.
4. Run NR power flow.
5. Determine if the constraints are being satisfied exempting, add the penalties and find the fitness function.
6. Till the specified no. of iterations, find the velocity of the particle, add the velocity of the earlier iteration result to access a new set of population, run NR power flow and calculate the fitness value as stated in the previous step.
7. Output the solution of the best generation pattern and terminate the process.

3 Symbiotic Organic Search Algorithm in Congestion Management

The term ‘Symbiosis’ was introduced by DeBary in 1878 which describes the conjugation behavior of dissimilar organisms in ecosystem. Symbiosis is derived from the greek word “living together” [21]. It refers to the relation between two different species that are interdependent gaining benefit from the other with the objective of increasing its fitness for survival in the ecosystem. SOS algorithm works in three phase: mutualism phase, commensalism phase and parasitism phase. Each phase is defined by the character of organisms involved in the interaction. In mutualism phase, the interaction favors both the organisms; commensalism phase favors one organism and does not impact the else and as the name indicates parasitism phase favors one organism and harms the other. In SOS algorithm, the interacting organisms randomly move through all the three phases till the terminus condition is met.

Let X_m and X_n be two organisms in an ecosystem, selected randomly to connect in a mutualistic relationship.

3.1 Mutualism Phase

Depending on the mutualistic symbiosis between organism Xm & Xn, the new solutions or organisms created are given by,

$$X_{m,new} = X_m + rand(0,1) * (X_{best} - Mutualvector * BF_1) \tag{3}$$

$$X_{n,new} = X_n + rand(0,1) * (X_{best} - Mutualvector * BF_2) \tag{4}$$

$$\text{Mutualvector} = \frac{X_m + X_n}{2} \tag{5}$$

where, BF_1 and BF_2 are benefit factors of value either 1 or 2, random (0,1) is a vector of random numbers, mutualvector is the relationship characteristic between organisms X_m and $X_{n.}$, X_{best} is the highest degree of adaptability.

3.2 Commensalism Phase

The organism X_m is assumed to be benefited through interaction. As per the commensalism symbiosis the new solution is obtained by,

$$X_{m,new} = X_m + \text{rand}(-1, 1) * (X_{best} - X_n) \tag{6}$$

where $(X_{best} - X_n)$ represents the beneficial advantage afforded by X_n to aid X_m increasing its degree of survival in the ecosystem.

3.3 Parasitism Phase

The best example to realize the parasitism phase is the affliation of anopheles mosquito with human hosts. The parasite develops inside the human body while deteriorating its host with malaria. Similarly the organism X_m acts as a parasite and strives to replace the randomly selected organism X_n by generating a spurious parasite in search space called as "parasite-vector". This vector engages in substituting X_n in the ecosystem. While evaluating the fitness of both the organisms, if the parasite-vector has an exceptional or greater fitness value, it will wipe out and preserves its position in the ecosystem. On the other hand, if the organism X_n has superior fitness value, it will gain more immunity and parasite vector will not be capable to survive in that ecosystem (Table 2).

The step by step procedure in SOS algorithm is as follows,

1. Initialize the size of the ecosystem by considering the optimization parameters, maximum no. of iteration etc.…
2. Generate uniform random numbers ranging from lower ecosystem size to upper ecosystem size and calculate the fitness value.
3. Select the candidate which has the minimum fitness value as X_{best}.
4. Mutualism phase: Select organisms X_m and X_n from the ecosystem. Find the mutual vector from Eq. (5). Calculate the new organisms X_m and X_n from Eq. (3) and Eq. (4). Compare the new solutions with the older one. Select the fitter organisms to take part in the next iteration.
5. Commensalism Phase: Select any organism X_n randomly such that $X_n \neq X_m$. Calculate the new solution using Eq. (6). Compare the fitness of new solution with the former one. Replace the organisms with newer one if the fitness value is inferior otherwise retain the older one.

Table 2 SOS parameters

Parameter	Value
n	10
Max iteration	40

6. Parasitism phase: Select any organism X_n randomly from the ecosystem. Create parasite vector b interacting X_m in random dimensions between the prescribed lower and upper limits. Compare the fitness of parasite vector with selected organism X_n. Eliminate the one which has inferior fitness value and replace the value of the else one in the ecosystem.

4 Modeling of TCSC

Among various types of FACTS devices, series devices like TCSC [22, 23] plays a vital role in relieving transmission line congestion and aids in better operation of the existing system. As the FACTS devices are of high cost, its location in the power system and its parameter setting is of exceedingly important. In this paper, TCSC is modeled as a series capacitor.

Figure 1 shows the π-model of transmission line in which the parameters are lumped between two buses i and j. During static condition, TCSC is considered as a static reactance −jxc connected between buses i and j. The rating of the TCSC depends on the reactance of the transmission line where the TCSC is located.

$$X_{ij} = X_{line} + X_{TCSC} \tag{7}$$

where,

$$X_{TCSC} = -0.7X_{TCSC} \text{ to } 0.2X_{TCSC} \tag{8}$$

As per Wibowo et al. [24], the investment cost of TCSC is as follows,

$$IC = \frac{C_{TCSC} \times S_{TCSC} \times 1000}{8760} \$/hr \tag{9}$$

$$C_{TCSC} = 0.0015S^2_{TCSC} - 0.7130S_{TCSC}153.75\$/kVAR \tag{10}$$

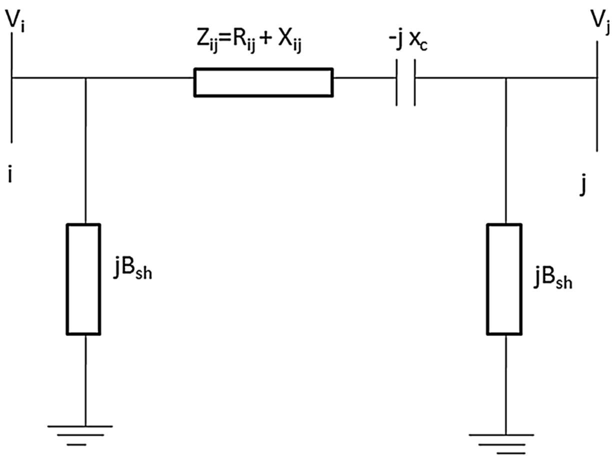

Fig. 1 TCSC located in transmission line

5 Wireless Technology

Being competitive, information interchange between utilities and ISO is necessitous to meet technical challenges. Sui et al. [25] has suggested an advanced metering infrastructure (AMI) which benefits the utilities to collect and exploit metered datas in perceptive aspect. The consumers can realize their electricity price, billing and prepayment alarm in case of abnormalities and so on. The AMI system utilizes multi communication media like global systems for mobile communications (GSM) and general package radio service (GPRS). Correspondingly the similar two way communication benefits during congestion management also.

Figures 2 and 3 depicts the schema of GPS and GPRS system respectively. When the system is subjected to congestion, the proposed method does simultaneous optimization of rescheduling the real power as well as locating TCSC at appropriate location. The optimized rescheduled data's are collected in collecting terminal unit which consists of microcontroller board, a backup battery and communication module such as GSM or GPRS. The microcontroller is decked with input–output interface and communication ports. Serial port devices such as RS. 232 or RS. 485 can be employed for this level of data transmission. This information can be transmitted through (1) GSM that can impart short message service (SMS) which is applicable for less data exchange applications or (2) GPRS that employs data rates in the range of 56–114 Kb/s and provides stable connection to the internet for mobile phone and computer users.

Henceforth the generating stations whose generators are to be rescheduled to alleviate congestion are thereby informed through wireless communication. Apart from GSM or GPRS, WiMax a long range wireless communication technique can also be used for this power applications.

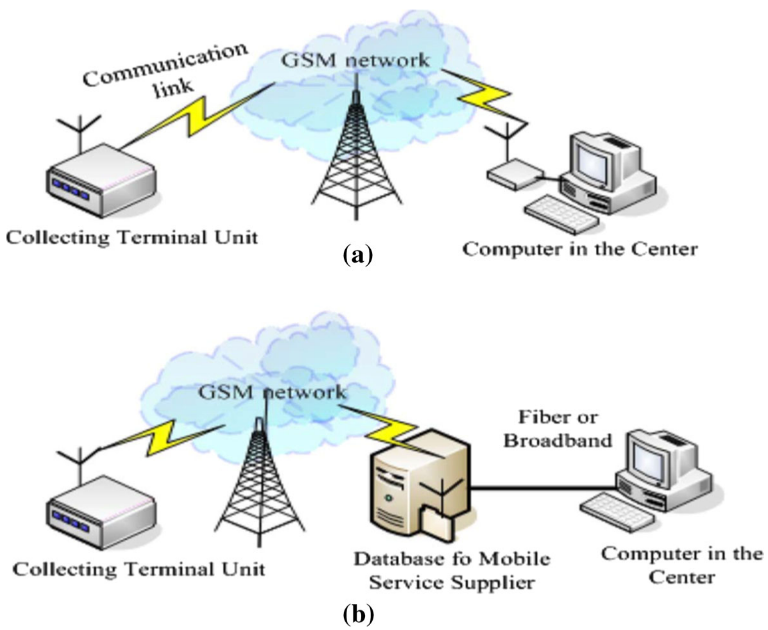

Fig. 2 Schematic of GSM network

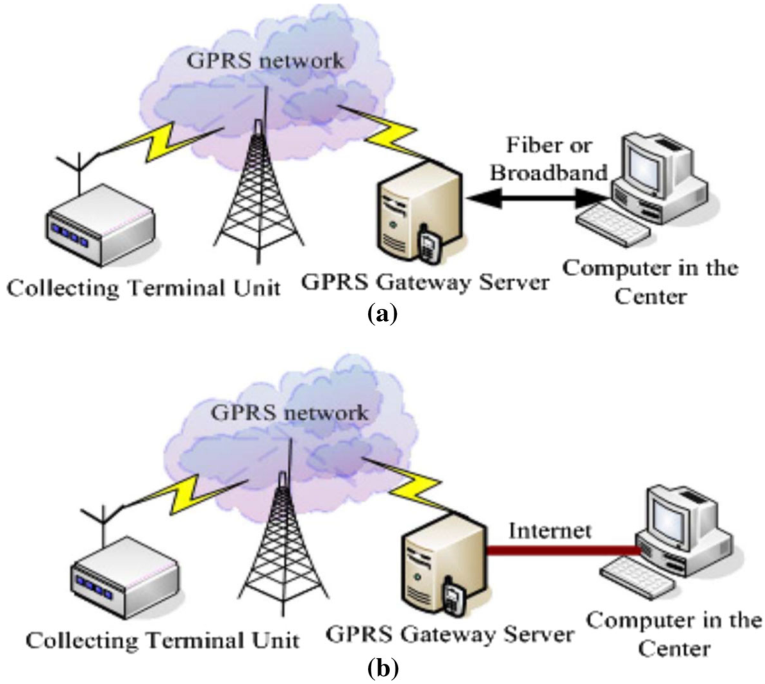

Fig. 3 Schematic of GPRS network

6 Problem Formulation

To solve congestion in the transmission line, the problem is formulated as a multi-objective optimization function in which, the congestion cost, the installation of TCSC and transmission losses are minimized simultaneously has been proposed. Based on this, the objective function is given as,

$$y = \min\left\{\sum_{i=1}^{N_G} C_{gi}\left(P_{gi}\right) - \sum_{i=1}^{N_D} B_{di}(P_{di}) + IC + P_{loss}\right\} \tag{11}$$

where, $C_{gi}\left(P_{gi}\right)$ is the cost function of generator at ith hour or generation bid; $B_{di}(P_{di})$ is the cost function of load at ith hour or demand bid; NG is the number of generators; N_D is the number of load; IC is the Installation cost of TCSC; P_{loss} is the transmission losses.

Subject to

6.1 Equality Constraints

$$P_{gi} - P_{di} = \sum_{j=1}^{N_g} |V_i||V_j||Y_{ij}|Cos\left(\delta_i - \delta_j - \theta_{ij}\right) \tag{12}$$

$$Q_{gi} - Q_{di} = \sum_{j=1}^{N_g} |V_i||V_j||Y_{ij}|Sin\left(\delta_i - \delta_j - \theta_{ij}\right) \tag{13}$$

6.2 Inequality Constraints

$$P_{gi,min} \le P_{gi} \le P_{gi,max} \tag{14}$$

$$Q_{gi,min} \le Q_{gi} \le Q_{gi,max} \tag{15}$$

$$P_{di,min} \le P_{di} \le P_{di,max} \tag{16}$$

$$Q_{di,min} \le Q_{di} \le Q_{di,max} \tag{17}$$

$$\mathrm{Vi, min, Vj, min} \le \mathrm{Vi, Vj} \le \mathrm{V}i\mathrm{, max, Vj, max} \tag{18}$$

7 Results and Discussion

The objective function given in Eq. (11) along with the constraints given in Eqs. (12)–(18) are solved with the PSO and SOS optimization algorithms. The proposed objective has been tested on IEEE 14 and IEEE 30 bus systems considering three congestion cases (1) bilateral transaction (2) multilateral transaction and (3) overloading. It results in the condition of modifying the transactions. Hence the entire system is divided into various zones depending on the sensitivity of line flows in the congested lines. To identify the sensitive generators PTCDF [26, 27] is employed.

7.1 IEEE 14 Bus Test System

This test system has five generators, fourteen buses, twenty transmission lines and eleven loads. The required data of IEEE 14 bus system is obtained from [27]. The bus system is divided into three zones in which cluster of buses and loads are grouped as a zone.

A bilateral transaction of 50 MW is carried out between a generator in zone-1 and a load in zone-2. The transaction results in some of the lines to operate beyond their limit and said to be congested. Some of the lines are given in Table 3. Lines 1, 2, 4 and 5 are found to be congested. After optimization with PSO and SOS algorithm, the line flows are reduced i.e., congestion has been relieved. It can be noticed that line flows are very much appreciable with SOS algorithm. During the multilateral transaction of 50 MW between generator in zone-1 and between the loads in zone-2 and zone-3, SOS algorithm performs better than the PSO algorithm.

Table 3 Comparison of line flows—bilateral transaction

Line no.	Line flows in MVA			
	Line flows limit	Without TCSC	Generation rescheduling with TCSC	
			PSO	SOS
1	120	128	119.45	119.85
2	65	75.6	66	64.9
4	65	82.3	65.01	65
5	50	54	50.11	50

Table 4 TCSC parameters

TCSC parameters	Optimal value	
	PSO	SOS
Optimal location	Line no. 7	Line no. 7
Compensation (K_{TCSC})	−0.5 p.u.	−0.47 p.u.
Mode of operation	Capacitive	Capacitive
Reactance (X_{TCSC})	−0.1102 p.u.	−0.1052 p.u.

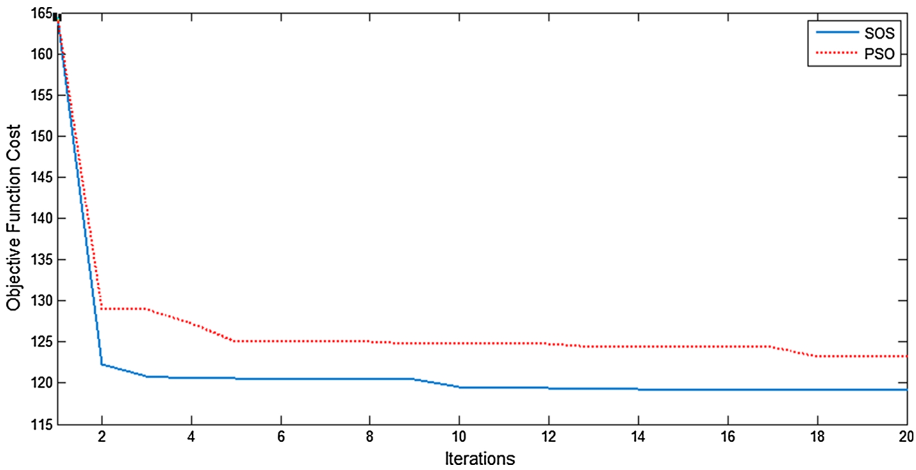

Fig. 4 Bilateral transactions

The ideal values for TCSC location, its parameter setting and the reactance values are tabulated in Table 4. It shows that to determine the optimal location of TCSC, the capacitive mode of operation is preferred. Both the optimization algorithms have propounded line no. 7 as the best location to place TCSC for alleviating congestion from the lines.

The capacitive reactance value and the compensation level are tabulated.

The graph showing congestion cost versus no. of iterations for various cases are listed below (Figs. 4, 5, 6).

The two algorithms are used to calculate the real power generation and losses occurring in 24 h. Table 5 depicts the line losses incurred at 100% loading. It is clear from the tabulation that optimizing with SOS produces comparatively less losses than PSO.

7.2 IEEE 30 Bus Test System

This test system has generators, thirty buses, forty-one transmission lines and twenty-one loads. The required data of IEEE 30 bus system is obtained from [28]. Identical with previous discussion, thirty bus system is also divided into three zones, in which cluster of buses and loads are grouped as a zone.

A bilateral transaction of 50 MW as in case of 14 bus system is carried out between a generator in zone-1 and a load in zone-2. The transaction of power makes some of the lines to operate beyond their limit and said to be congested. Some of the congested lines are

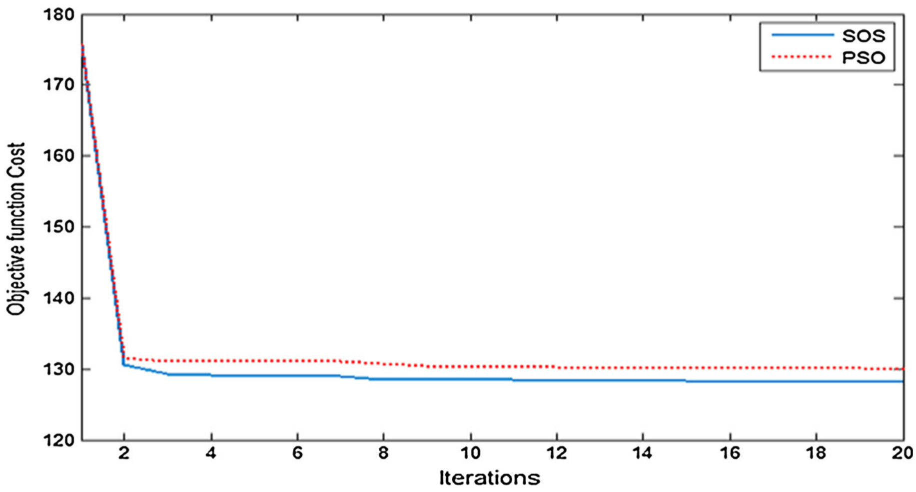

Fig. 5 Multilateral transactions

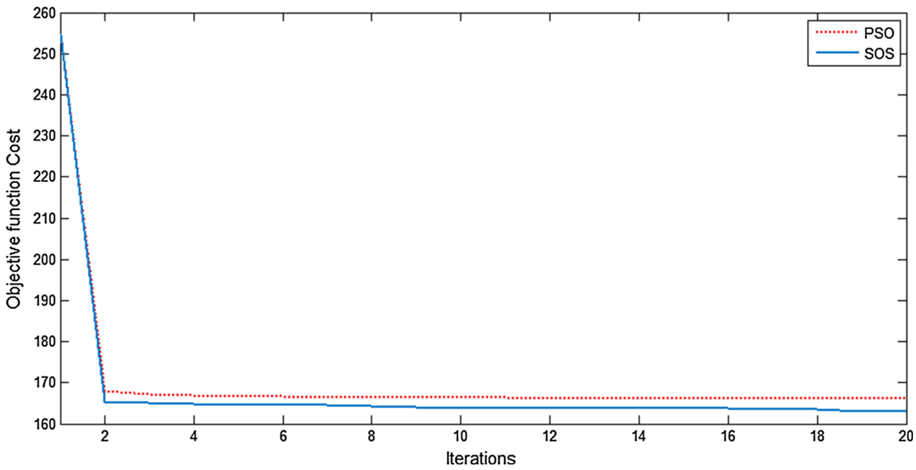

Fig. 6 50% overloading

Table 5 Comparison of Line losses in various cases

Bilateral transaction		Multilateral transaction		50% Overloading	
PSO	SOS	PSO	SOS	PSO	SOS
Line losses (KW)					
3.96	3.67	6.88	3.94	10.47	9.47

given in Table 6. Lines 1, 6, 13 and 14 are found to be congested. After optimization with PSO and SOS algorithm, the line flows are reduced i.e., congestion has been relieved. The effectiveness of SOS is revealed from Table 6 and can be noticed that line flows are very much substantial with SOS algorithm. During the multilateral transaction of 50 MW

Table 6 Comparison of line flows for Bilateral transaction

Line no.	Line flows in MVA			
	Line flows limit	Without TCSC	Generation rescheduling with TCSC	
			PSO	SOS
1	130	151.05	130.51	130.01
6	65	69.28	63.5	64.85
13	65	72	67.64	64.9
14	65	70	65.42	64.9

Table 7 TCSC parameters

TCSC parameters	Optimal value	
	PSO	SOS
Optimal location	Line no. 15	Line no. 15
Compensation (K_{TCSC})	−0.62 p.u.	−0.6 p.u.
Mode of operation	Capacitive	Capacitive
Reactance (X_{TCSC})	−0.1023 p.u.	−0.11 p.u.

between generator in zone-1 and between the loads in zone-2 and zone-3, SOS algorithm performs better than the PSO algorithm. Also some of the lines are randomly overloaded by 50% and the same inference has been achieved.

The optimal location of TCSC and its corresponding parameters to relieve the lines from congestion is tabulated in Table 7. It is found that the TCSC operates in capacitive mode with the reactance and compensation level as mentioned. Both the algorithm recommends line no. 15 to be the best location to place TCSC in order to meet the objective.

The following graphs showing congestion cost versus no. of iterations for various cases are listed below (Figs. 7, 8, 9).

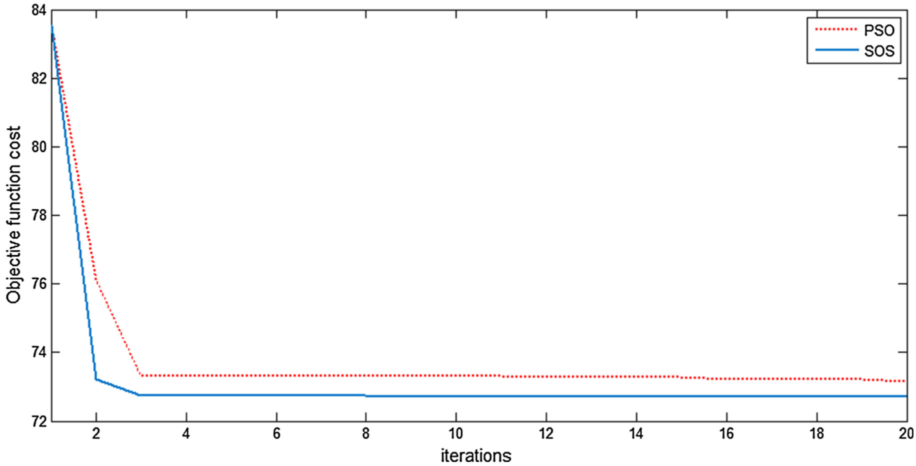

Fig. 7 Bilateral transaction

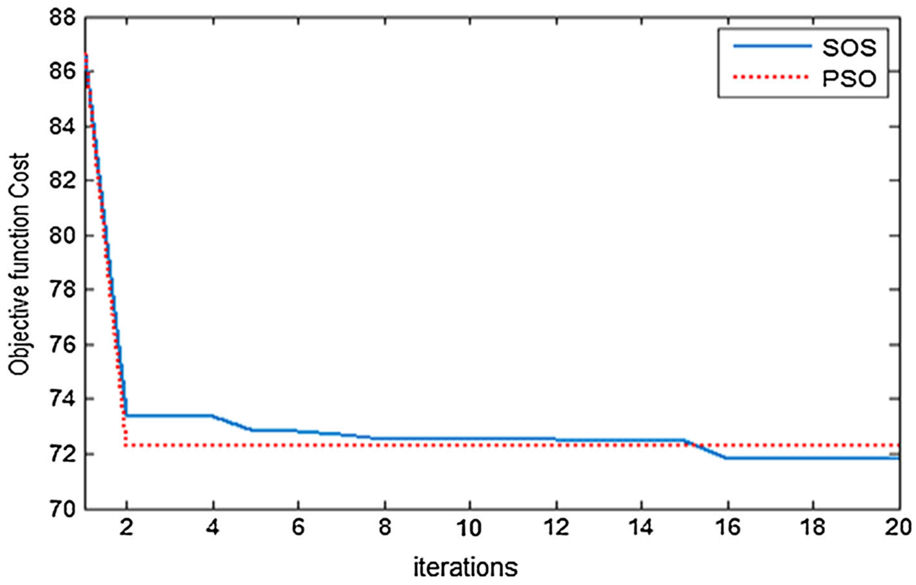

Fig. 8 Multilateral transactions

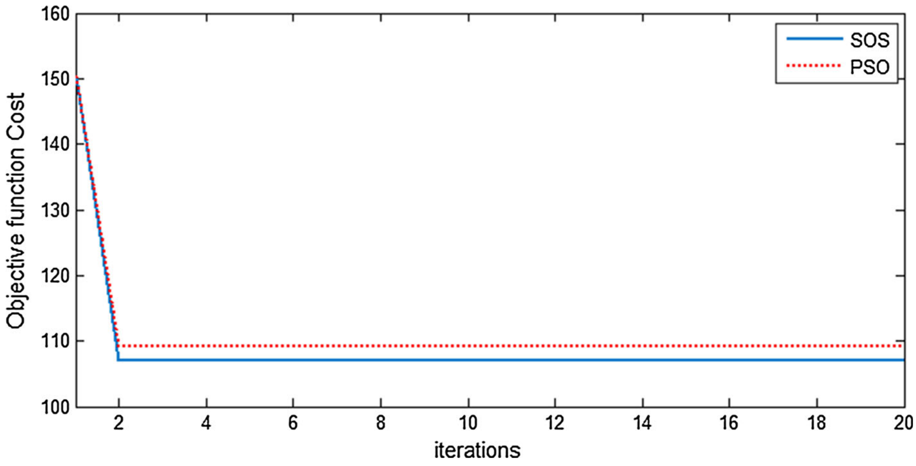

Fig. 9 50% overloading

Table 8 Comparison of Line losses in various cases

	Bilateral transaction		Multilateral transaction		50% Overloading	
	PSO	SOS	PSO	SOS	PSO	SOS
Line losses	3.73	3.72	3.877	3.8	4.968	4.804

The minimization of transmission line losses is one of the objectives, henceforth the line with 100% loading is considered to account. Both PSO and SOS algorithms are potent enough to minimize the losses in which SOS is found to be superior as indicated in Table 8.

8 Conclusion

The optimization algorithms in relieving congestion along with generation scheduling with TCSC is presented. The proposed objective is tested on IEEE 14 and IEEE 30 bus system for various congestion cases. The minimization of congestion cost and losses reveal that both the algorithms are superior enough to solve this simultaneous multiobjective optimization problem, SOS being the best.

References

1. Lai, L. L. (2002). *Power system restructuring and deregulation*. Chichester: Wiley.
2. Singh, D., & Verma, K. S. (2011). GA- based congestion management in deregulated power system using facts devices. 1109/ICUEPES, 2011. 6497716.
3. Acharya, N., & Mithulananthan, N. (2007). Locating series FATS devices for congestion management in deregulated electricity markets. *Electric Power Systems Research, 77*, 352–360.
4. Khan, M. T., & Siddiqui, A. S. (2014). Congestion management in deregulated power system using FACTS device. *International Journal of System Assurance Engineering and Management*. doi:10.1007/s13198-014-0258-x.
5. Mandala, M., & Gupta, C. P. (2013). Optimal placement of TCSC for transmission congestion management using hybrid optimization approach. In *IEEE, international conference on IT convergence and security* (pp. 1–5). ISBN: 14047577.
6. Besharat, H., & Taher, S. A. (2008). Congestion management by determining optimal location of TCSC in deregulated power systems. *Electric Power and Energy Systems, 30*, 563–568.
7. Ushasurendra, S., & Parthasarathy, S. S. (2012). Congestion management in deregulated power sector using fuzzy based optimal location technique for series flexible alternative current transmission system (FACTS) device. *Journal of Electrical and Electronics Research, 4*(1), 12–20.
8. Hazra, J., & Singh, A. K. (2007). Congestion management using multiobjective particle swarm optimization. *IEEE Transactions on Power Systems, 22*(4), 1726–1734.
9. Mishra, A., & Gundavarupu, V. N. K. (2015). Line utilization factor based optimal allocation of IPFC and sizing using firefly algorithm for congestion management. *IET Generation, Transmission and Distribution*, 1–8. doi:10.1049/iet-gtd.2015.0493.
10. Hooshmand, R. A., Morshed, M. J., & Parastegari, M. (2015). Congestion management by determining optimal location of seires FACTS devices using hybrid bacterial foraging and Nelder–Mead. *Applied Soft Computing, 10*(106), 57–58.
11. Reddy, S. S., Kumari, M. S., & Sydulu, M. (2009). Congestion management in deregulated power system by optimal choice and allocation of FACTS controllers using multi-objective genetic algorithm. *Journal of Electrical Engineering & Technology, 4*(4), 467–475.
12. Reddy, K., Reddy, S., Padhy, N. P., & Patel, R. N. (2006). Congestion management in deregulated power system using FACTS devices. In *IEEE power india conference*. doi:10.1109/POWERI.2006.1632541.
13. Acharya, N., & Mithulananthan, N. (2007). Locating series FACTS devices for congestion management in deregulated electricity markets. *Electric Power Systems Research, 77*, 352–360.
14. Yesuratnam, G., & Thukaram, D. (2007). Congestion mangement in open access based on relative electrical distance using voltage stability criteria. *Electric Power Sytem Research, 77*, 1608–1618.
15. Sarwar, M., & Siddiqui, A. S. (2015). An efficient particle swarm optimizer for congestion management in deregulated electricity market. *Journal of Electrical Systems and Information Technology, 2*, 269–282.
16. Kirthika, N., & Balamurugan, S. (2016). A new dynamic control strategy for power transmission congestion management using series compensation. *Electrical power and energy systems, 77*, 271–279.

17. Krishnasamy, V., & Jegatheesan, R. (2013). Optimal location of multiple TCSC for congestion management. In *Proceedings on IEEE conference on power engineering and optimization conference*.
18. Sophia Jasmine, G., & Vijayakumar, P. (2014). Congestion management in competitive power market using TCSC. *ARPN Journal of Engineering and Applied Sciences, 10*(9), 4271–4274.
19. Kennedy, J., Eberhart, R. C., & Shi, Y. (2001). *Swarm intelligence*. SanFrancisco: Morgan Kaufman Publishers.
20. Bonabeau, E., Do Ringo, M., & Theraulaz, G. (1999). Swarm intelligence: from natural to artificial systems, Oxford University Press, Santa Fe Institute studies in the science of complexity.
21. Cheng, M. Y., & Prayogo, D. (2014). Symbiotic organisms search: A new metaheuristic optimization algorithm. *Computers & Structures, 10*(1016), 98–112.
22. Hingorani, N. G., & Gyugyi, L. (1998). Understanding FACTS. The Institution of Electrical and Electronics Engineers.
23. Hingorani, N. G. (1998). High power electronics and flexible AC transmission system. In *Proceedings of the American Power Conference* (Vol. 50). ISSN 0097-2126.
24. Wibowo, R. S., Yorino, N., Eghbal, M., Zoka, Y., & Sasaki, Y. (2011). FACTS devices allocation with control coordination considering congestion relief and voltage stability. *IEEE Transactions on Power System, 26*(1), 2302–2310.
25. Sui, H., Wang, H., Lu, M. S., & Lee, W. J. (2009). An AMI system for the deregulated electricity markets. *IEEE Transactions on Industry Applications, 45*(6), 2104–2108.
26. Muneender, E., & Vinod Kumar, D. M. (2009). A zonal congestion management using PSO and real coded genetic algorithm. In *IEEE conference on power systems and expositions*, 978-1-4244-3811-2/2009.
27. http://www2.ee.washington.edu/research/pstca.
28. Kumar, A., Srivatsa, S. C., & Singh, S. N. (2004). A zonal congestion management approach using real and reactive power rescheduling. *IEEE Transactions Power Systems, 19*(1), 554–562.

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