

CONGESTION MANAGEMENT IN DEREGULATED POWER SYSTEM INCORPORATING SOFT COMPUTING TECHNIQUES

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Abstract:In the competing power market, congestion is one of the technical concerns in transmission lines which threaten the system security. Its solution technique, congestion management is the most significant element of Independent System Operator (ISO). It is the responsibility of ISO to endorse a corrective action so as to alleviate congestion without disturbing the security of the system. Besides, the problem of congestion contributes to the electricity price surge that propagate incompetent market environment. Thus, the need for an exceptional solution technique that would take care of all the risks in the power market, has become the need of the hour. One such solution methodology is proposed in this paper. Here, an optimization based solution methodology to relieve congestion both by rescheduling the generation as well as locating series FACTS device, Thyristor Controlled Series Compensator (TCSC) in the congested line is discussed. The proposed objective function being non-linear, is solved using Particle Swarm Optimization (PSO) and Biogeography Based Krill Herd (BBKH) algorithms. The effectiveness of both the optimization techniques was compared to various parameters. The proposed objective was verified on IEEE 30 bus and Indian Utility 75 bus systems.

Keywords: Congestion, deregulated power system, FACTS device, TCSC, PSO, BBKH.

1. INTRODUCTION

The unbundling of power system layout due to privatization of electricity sector, has a massive consequence on the entire power system throughout the globe. Deregulation or privatization makes the electricity market perplexed and competitive with too many participants who tend to sell and buy electrical power. This multi-participant market structure is characterized by contracted power and monetary transactions which cannot guarantee the operation of transmission lines within their operating limits. When there is lack of co-ordination between buyer and seller of electric power, congestion occurs in the transmission lines. Other causes are due to the pursuit of transmission lines nearer to or above its thermal limits so as to supply the exaggerated power consumptions and contracts [1]. Exempting it, may induce a series of failures that cannot be controlled. Congestion management is probably the most important management crisis that would occur in the transmission system. It is substantially controlling the transmission system such that the operating limits are observed [2]. In recent day power market, the individual utility follows its own

convention and regulations to manage congestion in the system[3]. Limitations that emanate from environmental, economical and right of way obstruct the establishment of new transmission lines but permits better utilization of existing system by incorporating FACTS devices. It promotes the performance of the system considerably by regulating the power flows in the network [4]. Incorporation of such FACTS devices in the system is considered to be an effective approach to subside the transmission congestion as well as to upgrade the accessible transfer capability. Recently interest towards these devices has increased due to couple of reasons. The contemporary evolution in power electronics has driven these devices cost efficient and aggravated loading associated with deregulation in power system, provokes the power flow control mechanism as a worthwhile resource of dispatching scheduled power transactions.

Several research works are found in various literatures in relation to the current work. Authors in [5] have proposed GA based optimal power flow method for locating SVC and UPFC device in the system to relieve congestion. In [6], the authors described the technique based on real power performance index and reduction of total system VAR power losses to mitigate congestion. The scenario of series compensation in relieving congestion is explained in [7-9]. Rescheduling real and reactive power of generators in order to mitigate congestion in the line is considered based on adaptive fuzzy PSO[10], real coded genetic algorithm[11] and transmission congestion distribution factor[12,13]. In [14], the problem of congestion management is elucidated as a multi-objective optimization problem, employing multi-objective mathematical programming approach based on normalized normal constraint(NNC) method. Alleviating congestion along with voltage stability enhancement is proposed in [15, 16]. Rescheduling real power of generators using relative electrical distance and cluster/zone method are proposed in [13,16]. The significance of FACTS devices in relieving transmission congestion is illustrated in [17-20].

In this paper, congestion is considered as a multi-objective optimization problem. Three parameters namely, (i) the congestion cost (ii) installation cost of TCSC and (iii) line losses are simultaneously minimized. The effectiveness of PSO and BBKH algorithm in solving this chaotic optimization problem is revealed in this paper. The most cogent generators are rescheduled based on the values of real and reactive transmission congestion distribution factors.

The paper is organized as follows, the concept of PSO and BBKH along with its contribution in relieving congestion is explained in section 2 and section 3 respectively. Modeling of TCSC is summarized in section 4. Problem formulation is detailed in section 5. Case studies and results are discussed in section 6 followed by a brief conclusion in section 7.

2. PARTICLE SWARM OPTIMIZATION

PSO was first implemented by Kennedy, et.al [21]. It is a speculative algorithm known for its accuracy and rapid convergence [22]. Irrespective of the field of interest, PSO provides a moderate solution for any kind of incoherent

problems. PSO engrosses the flying of swarm of birds moving in search of food. In the entire search space, every individual is termed as a particle. When every particle progress throughout the entire search space, the best position achieved by it, is called as global minimum (or maximum), gbest. At every instant during its travel, the velocity of each particle is regulated and restored to its latest position in accordance with its personal experience and of its adjacent particles.

In each generation of population, a couple of parameters are modified for every particle. The parameters are, the pre-eminent position or fitness value the particle has acquired which is termed as the position best (pbest), $P_i = (p_{i1}, p_{i2}, \dots, p_{in})$ and the pre-eminent position acquired by some other particle termed as global best (gbest), $G_i = (g_{b1}, g_{b2}, \dots, g_{bin})$. Based on the particle's pbest and gbest values, the velocity and position modification of every particle is accomplished using equations (1) and (2) respectively.

$$V_i^{k+1} = \omega * V_i^k + C_1 * rand_1 * (P_i^k - X_i^k) + C_2 * rand_2 * (gb^k - X_i^k) \quad (1)$$

$$X_i^{k+1} = X_i^k + V_i^{k+1} \quad (2)$$

where, ω signifies inertia weight,

rand 1 and rand 2 stands for random values either 0 or 1,

C_1 & $C_2 = 2$ are acceleration constants and k is the iteration number.

The PSO parameters used in this work are listed in Table.1

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

The procedure of PSO algorithm is as follows,

1. Get the transmission line data, bus data and other data from the respective bus system and PSO parameters.
2. Impress congestion in the bus system (using considered congestion cases) and perform load flow analysis for the specified generation and load condition.
3. Create a random set of control variables using PSO such as incremental and decremental generation values, TCSC parameters satisfying the operating limits.
4. The obtained values are imposed in the system data.
5. Perform load flow analysis again.

6. Verify if the operating constraints are being satisfied and if not, include the penalties and calculate the fitness function.
7. Update the position and velocity of each particle and find the best individual at every generation till the stopping criteria is attained.
8. Obtain the values of the best generation and stop the process.

3. BIO-GEOGRAPHY BASED KRILL HERD OPTIMIZATION ALGORITHM

Bio-geography based Krill herd (BBKH) is one among the novel search based heuristic optimization algorithm. Krill (KH) method proposed by [23] and biogeography based optimization (BBO) method proposed by [24]. The objective function endorsed in krill herd method is based on the least distance of krill from its food and the maximal herd density. KH method depends on the random movement of the krill and it fails to converge to the satisfactory value when trapped in its local optima. To enhance this exploitation ability of KH, an upgraded habitat migration (KM) operator is added with KH to achieve an efficient biogeography based krill herd approach. The migration operator is a random operator which updates the position of krill (x_m). Every m^{th} position of krill x_m is associated with its immigration rate (λ_m) and emigration rate (μ_n). The position of every krill is influenced by three operations namely, (i) movement of other krill (N_m) (ii) foraging action (F_m) and (iii) physical diffusion (D_m). The Lagrangian model [25] of these actions are summarized as,

$$\frac{dx_m}{dt} = N_m + F_m + D_m \quad (3)$$

The position of the krill is characterized by the direction (α_m) in which it advances and it is composed of three parts or effects namely target, local and repulsive. Considering N_{max} as the maximum speed, ω_n as the inertia weight and $N_{m,\text{old}}$ as the previous movement of the krill, the new movement is given by,

$$N_m^{\text{new}} = N_{\text{max}}\alpha_m + \omega_n N_m^{\text{old}} \quad (4)$$

The foraging action is estimated using two elements namely, the food locality and its earlier experience. For the m^{th} krill,

$$F_m = V_f(\beta_m^{\text{food}} + \beta_m^{\text{best}}) + \omega_f F_m^{\text{old}} \quad (5)$$

where, V_f signifies the foraging speed,

ω_f stands for the inertia weight,

F_m^{old} the previous foraging value.

The physical diffusion is a random mechanism which depends on the highest diffusion speed and a random directional vector. If D_{max} is the maximum diffusion speed and δ represents the random directional vector. The mathematical expression for physical diffusion is formulated as,

$$D_m = D_{\max}\delta \quad (6)$$

Mathematically, in krill-herd method, position of krill is given by,

$$X_m(t + \Delta t) = X_m(t) + \Delta t \cdot \frac{dX_m}{dt} \quad (7)$$

The parameters of BBKH are furnished in Table.2

Table.2 BBKH parameters

Parameter	Value
np	20
Maxiter	20
V _f	0.2
D _{max}	0.005
N _{max}	0.01
P _{mod}	0.5
ω _f	0.3
ω _n	0.3
μ	0.3

BBKH algorithm in solving congestion management is as follows,

1. Input the line, bus data of the given system.
2. Initialization phase: Initialize the generation count $g=1$, random population of krill (p), V_f , D_{\max} , N_{\max} , δ_{\max} and P_{mod} .
3. Impress congestion in the considered bus system and run NR load flow program corresponding to the specified generation and load pattern.
4. Evaluate the fitness of each krill.
5. Sort from best krill to worst krill. Perform the calculation of three motions for each krill using (4),(5) &(6).

Update the position of the krill using (7).

6. Replace the best krill in the position of worstkrill. Sort the krill and identify the best krill in current generation.
7. Increment generation count $g=g+1$
8. Repeat steps 4 to 7 till the best krill or the best solution is achieved.

4. MATHEMATICAL FORMULATION

4.1 TCSC modelling

TCSCs are the pre-eminent devices of the FACTS group. The concept of FACTS proposed in [26-28], facilitates its flexible power transfer capability, thereby operating the transmission lines till their maximum thermal limit. It behaves like series of compensators with minimal harmonic distortions and losses. These devices constitute a capacitor bank in parallel with a thyristor controlled reactor. Amidst various FACTS devices, TCSC finds its application in improving the transfer capability of the system by varying the reactance of the line. TCSC modifies the reactance of the transmission line, thus affording inductive or capacitive compensation respectively. The rating of TCSC (X_{TCSC}) is articulated as the function of line reactance of where it is placed.

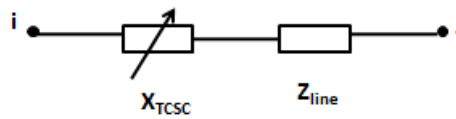


Fig.1 Mathematical model of TCSC

If Z_{line} is the reactance of the transmission line, it could be mathematically represented from Figure 1 as follows,

$$X_{ij} = Z_{line} + jX_{TCSC} \quad (8)$$

where, X_{TCSC} ranges from $-0.7 X_{line}$ to $0.2 X_{line}$. [29,30].

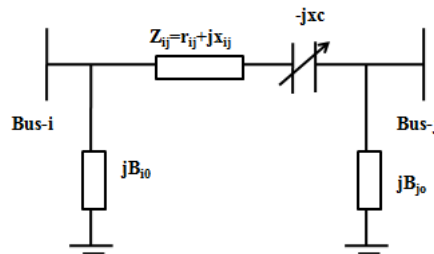


Fig.2 Location of TCSC in the transmission line

It is very much indispensable to speculate the location for the placement of TCSC due to its extensive costs. Figure 2 represents the π equivalent representation of a line connected between buses i and j. By steady state analysis, TCSC is regarded as a static capacitor whose reactance is given by $-jX_c$. It is mandatory to optimally locate TCSC in order to obtain its entire benefits because of the following reasons.

- It is very expensive.
- Unless it is optimally placed, it may have devastating effect on the system's stability.
- In deregulated market structure, it may reduce the profit of some participants.
- Location of TCSC in a sample 6 bus system by trial and error method is narrated in [31].

4.2 Real power transmission congestion distribution factors (PTCDF)

The variation in the value of real power flow, ΔP_{ij} through a transmission line- l which is connected between buses i and j respectively. By virtue of unit change in real power injection, ΔP_n at any bus n is defined as the real power transmission congestion distribution factors (PTCDF). Mathematically, the PTCDF for a line- l is represented as,

$$PTCDF_n^l = \frac{\Delta P_{ij}}{\Delta P_n} \quad (9)$$

The proposed method minimizes three parameters simultaneously. In the deregulated system, during power transactions or at overload, transmission lines are subjected to congestion. ISO manages the generator and demands bids and intends to reschedule the real power generation so as to mitigate the congestion. The congestion cost tends to rise during transactions and its minimization is the primary objective parameter. At the same time, in order to regulate the power flow as well as to minimize the transmission losses, TCSC is incorporated into the system. As the cost of TCSC is high, its parameter setting and its location need to be optimized. Hence, the cost minimizations as well as losses minimization are also embodied in the objective function.

The objective function of the proposed method eq.9 is formulated as follows,

$$y = \min\{\sum_{i=1}^{N_g} C_{gi}(P_{gi}) - \sum_{i=1}^{N_D} B_{di}(P_{di}) + IC + P_{loss}\} \quad (10)$$

Equality constraints:

$$P_{gi} - P_{di} = \sum_{j=1}^{N_g} |V_i||V_j||Y_{ij}|\cos(\delta_i - \delta_j - \theta_{ij}) \quad (11)$$

$$Q_{gi} - Q_{di} = \sum_{j=1}^{N_g} |V_i||V_j||Y_{ij}|\sin(\delta_i - \delta_j - \theta_{ij}) \quad (12)$$

Inequality constraints:

$$P_{gi,\min} \leq P_{gi} \leq P_{gi,\max} \quad (13)$$

$$Q_{gi,\min} \leq Q_{gi} \leq Q_{gi,\max} \quad (14)$$

$$P_{di,\min} \leq P_{di} \leq P_{di,\max} \quad (15)$$

$$Q_{di,\min} \leq Q_{di} \leq Q_{di,\max} \quad (16)$$

$$V_{i,\min} \leq V_i \leq V_{i,\max} \quad (17)$$

The installation cost of TCSC is given by,

$$IC = \frac{C_{TCSC} \times S_{TCSC} \times 1000}{8760} \text{ \$/hr} \quad (18)$$

The cost function of TCSC[19] is given by,

$$C_{TCSC} = 0.0015S_{TCSC}^2 - 0.7130 S_{TCSC} + 153.75 \frac{\$}{\text{kVAR}}(19)$$

Here, $C_{gi}(P_{gi})$ represents the cost function of generator or generation bid, $B_{di}(P_{di})$ represents the cost function of load or demand bid, N_G represents the generating units, N_D represents the number of loads, IC represents the installation cost of TCSC, P_{loss} is the loss occur in transmission lines, P_{gi} and P_{di} are the real power generated and real power demand respectively, Q_{gi} and Q_{di} are the reactive power generated and reactive power demand respectively, V_i , V_j are the voltages at i^{th} and j^{th} buses connecting a line respectively and S is the operating range of TCSC. The cost of TCSC is high, so, its parameters and location in the line should be optimized.

5. SIMULATION RESULTS

The problem of congestion is developed as a multi-objective optimization problem that is represented by the objective function, equality and inequality constraints given by equations (10),(11),(12) and(13-19) respectively. The problem is solved using PSO and BBKH optimization algorithms. The intended objective has been enforced on IEEE 30 bus system and Indian utility- 75 bus system considering the three congestion cases (i) bilateral transaction (ii) multilateral transaction and (iii) overloading. Because it results in the modification of the transactions, the entire system is divided into various zones depending on the sensitivity of line flows in the congested lines. Real power transmission distribution factor (PTCDF) [11] is used to identify the sensitive generators to take part in rescheduling. The entire bus system is divided into three zones depending on the sensitivity of power flow in the congested line. Based on the PTCDF value Eq.(9), zones are allocated manually and transactions are done between inter zones. Buses with high PTCDF values are grouped as zone-1 whereas buses with small PTCDF values are grouped into higher type of zone namely zone-2 and zone-3. The simulation cases and results are discussed as follows.

5.1 IEEE 30 bus system

IEEE 30 bus system has 6 generating units, 30 buses, 41 transmission lines and twenty one loads. The required data of IEEE 30 bus system is obtained from [32]. To validate the efficacy of the proposed methodology, three congestion cases [33] are considered. Their discussion is as follows,

Case (i) Consider a bilateral transaction between generator bus 2 and load bus 4. The bilateral power transaction creates congestion in few lines. Figure 3(a) reveals that the lines 1,6,13 and 14 are congested. After optimization with PSO and BBKH algorithm, the line flows are reduced i.e., congestion has been relieved. The effectiveness of BBKH is revealed from figure4 and can be noticed that the line flows are very much substantial with BBKH algorithm.

Case (ii) Consider a multilateral transaction of 50 MW between generator bus and load bus 4 and 5. Congestion could be observed in lines 1, 2, 3,4,5,9 and 11. BBKH algorithm performs better than the PSO algorithm which is depicted in figure 3(b).

Case (iii) The demand at the load buses are increased by 50% and the same deduction has been observed. It is shown in figure 3(c).

The optimal location of TCSC and its corresponding parameters to relieve the lines from congestion is tabulated in figure 4. It is found that TCSC operates in capacitive mode with the compensation level as mentioned. Sensitivity index is used to optimally find the location of TCSC. The line with most positive index is considered as the best place to locate TCSC. Both the algorithm recommends line no. 21 to be the best location to place TCSC in order to meet the objective. Figure 5 reveals that the algorithm minimizes the cost of generation. Minimization of transmission line losses is one of the proposed objectives and the efficiency of BBKH algorithm to achieve the objective depicted in figure 6. To analyze, the line with 100% loading is taken into account. It is evident that BBKH algorithm is adequately effective to minimize the transmission losses as well as the cost of generation.

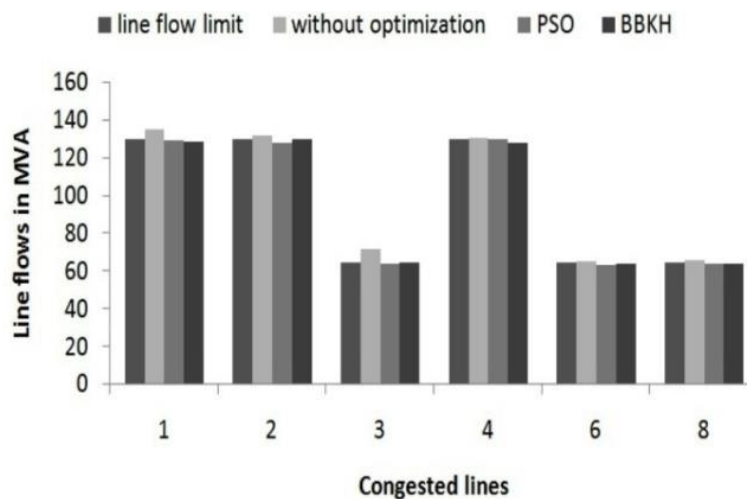


Fig 3(a) Comparison of power flows-bilateral transaction

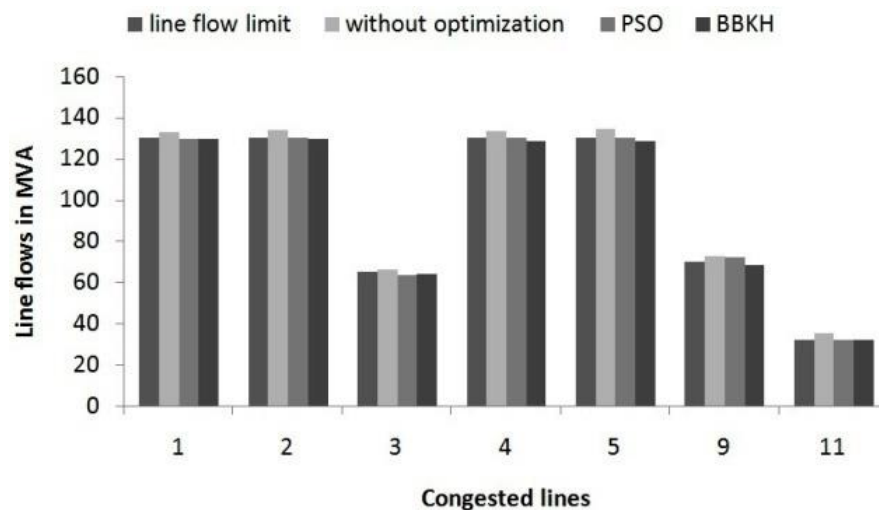


Fig 3(b) Comparison of power flows-multilateral transaction

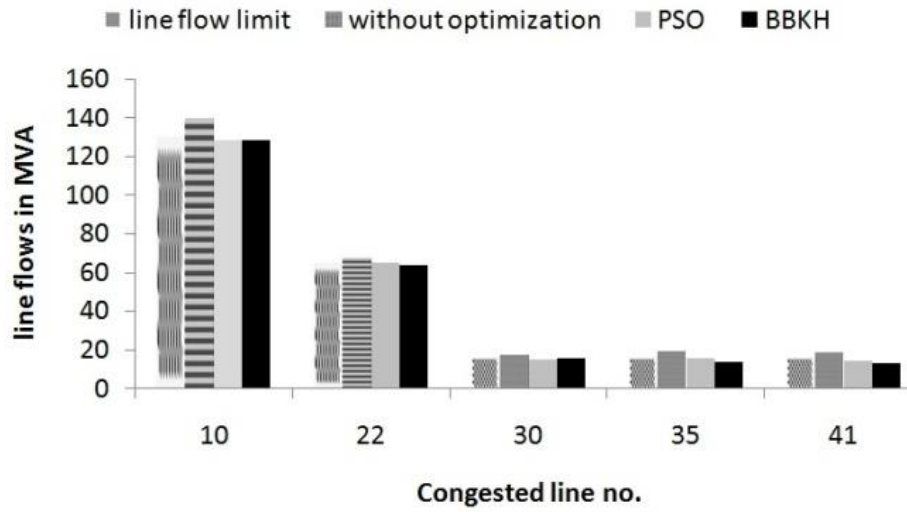


Fig 3(c) Comparison of power flows-overloading

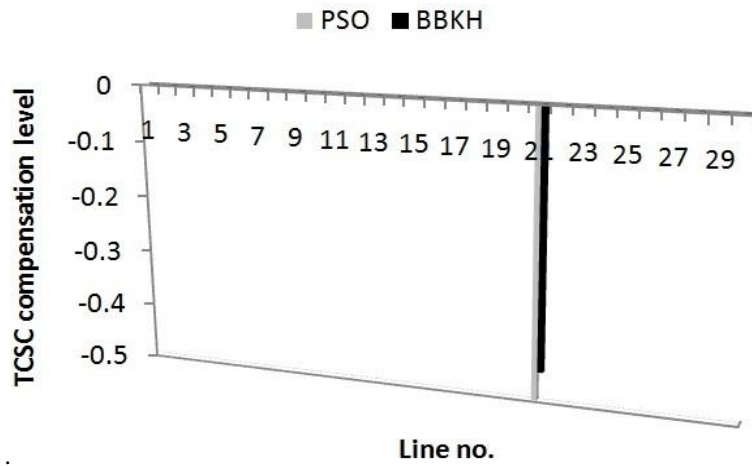


Fig 4 TCSC location

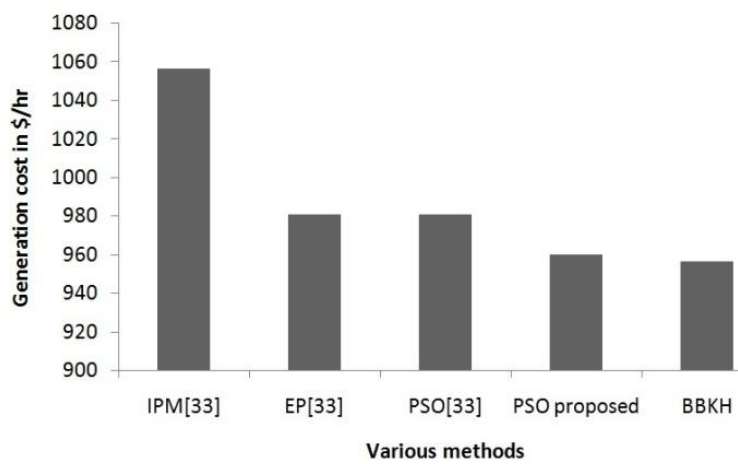


Fig 5 Comparison of generation cost

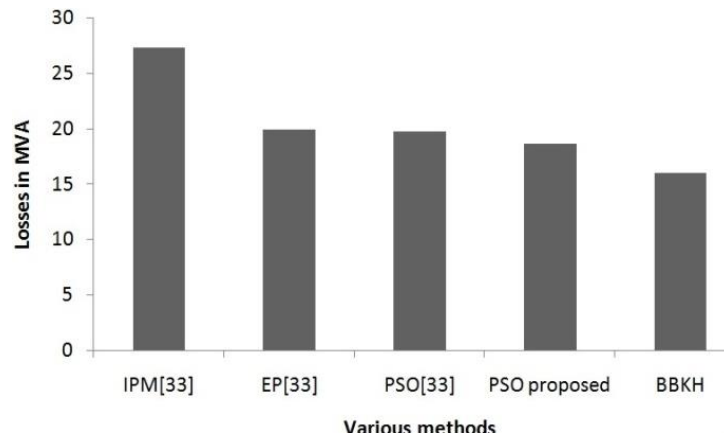


Fig 6 Comparison of losses

5.2 Indian Utility 75 bus system

It is a 132/33 kV transmission system with 15 generators, 75 buses and 60 load buses. PSO and BBKH approach in relieving congestion imposed in 75 bus system is as follows. Three congestion cases such as bilateral, multilateral and overloading are examined in this work.

Case (i)

A bilateral transaction of 50MW is transacted between a generator bus (bus no.6) and a load bus (bus no. 32). Due to this transaction, few lines are subjected to operate beyond their limits and said to be congested. Line nos. 57, 58 and 98 were found to be severely congested owing to the bilateral transactions. As per the proposed objective, BBKH alters the reactance of the line by including TCSC in its best location such that the transmission lines are free from congestion along with minimization in transmission losses. The most congested lines and the line flows before and after incorporating BBKH algorithm is given in figure 7(a).

Case (ii)

A multilateral transaction of 50 MW is carried out between generator bus 6 and load buses 32 and 39. The transaction results in the congestion of certain lines and figure 13 depicts the effectiveness of BBKH in relieving congestion. The most severely congested lines alone are tabulated. The lines are relieved from congestion after incorporating BBKH and the line flows are well maintained at a safer limit which could be seen from figure 7(b).

Case (iii)

In this case, congestion is imposed in the transmission line by increasing the total demand by %. Some of the lines were found to be congested and the most congested lines are represented in figure 7(c). TCSC alters the reactance of the transmission line such that the power flow is regulated without violating the line limits and hence congestion is mitigated. At the same time, the generators are rescheduled if necessary.

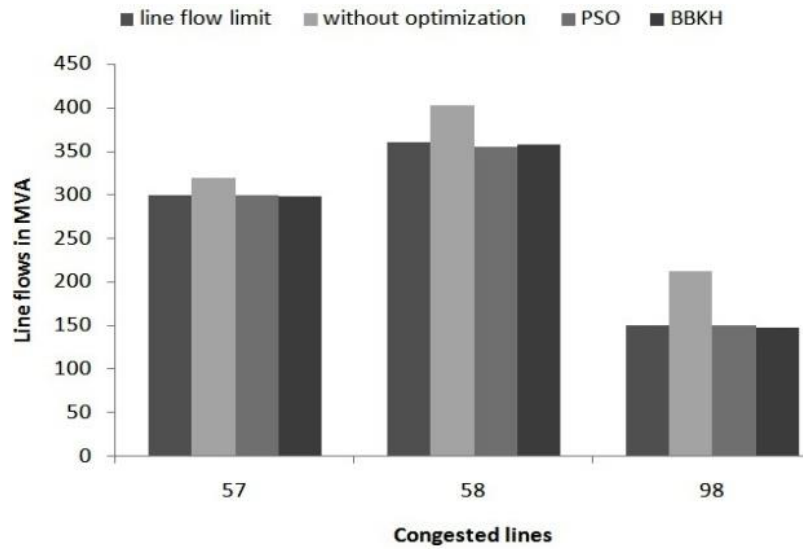


Fig 7(a) Line flows in 75 bus system due to bilateral transaction

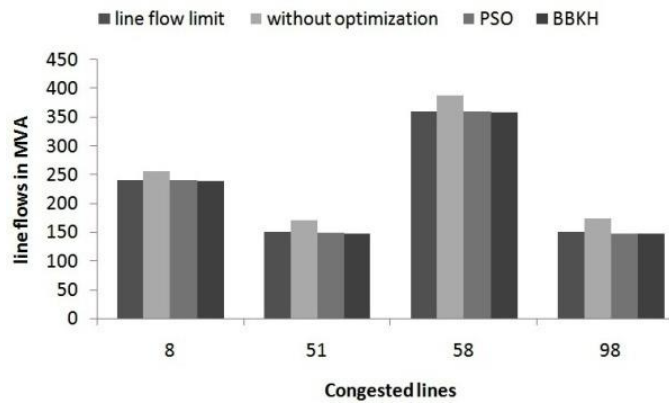


Fig 7(b) Line flows in 75 bus system due to multilateral transaction

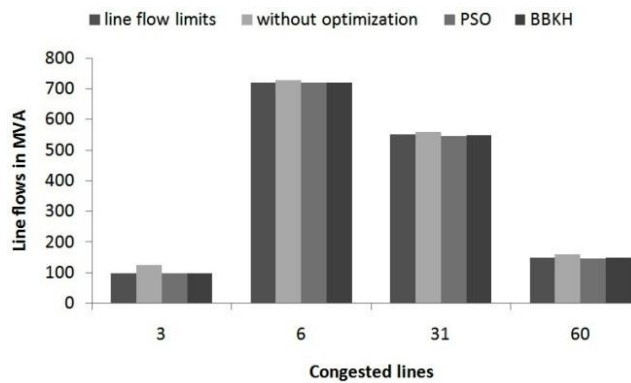


Fig 7(c) Line flows in 75 bus system due to overloading

It is clear from figure 8, that TCSC operates in capacitive mode in order to manage congestion in the lines. The reactance value and the compensation level are also mentioned. For bilateral, multilateral transactions

and overloading, the algorithm proposes line no. 58, 51 and 83 respectively as the suitable position to place TCSC in order to meet the objective. One of the measures to decide the optimal location of TCSC in a transmission line (between buses i and j) is the sensitivity index a_{ij} . The line with most positive index is considered as the optimal location to place TCSC. The algorithm calculates the sensitivity index of the lines and based on that value, the optimal location of TCSC is obtained. Table 3 depicts the sensitivity index obtained by BBKH algorithm.

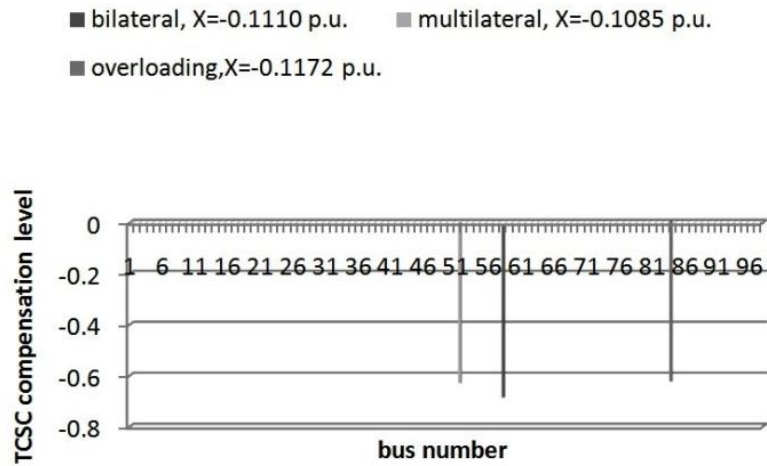


Fig 8 TCSC Parameters for various congestion cases

Table 3 Sensitivity index of 75 bus system for chosen lines at various cases

Bilateral		Multilateral		Overloading	
Line no. From bus, i-To bus, j	a_{ij}	Line no. From bus, i-To bus, j	a_{ij}	Line no. From bus, i-To bus, j	a_{ij}
13 (28-4)	-0.01377	36(27-51)	-0.01041	37(51-52)	-0.00052
19(24-10)	-0.00853	41(54-28)	-0.01834	41(54-28)	-0.00775
30(23-29)	-0.00690	51(59-39)	-0.00108	56 (61-62)	-0.00863
58 (31-32)	-0.00146	79(20-66)	-0.08825	67 (74-73)	-0.00755
73 (38-29)	-0.04861	81 (24-67)	-0.00776	83(18-71)	-0.00021
74 (38-22)	-0.00506	95 (21-30)	-0.00995	97(35-41)	-0.00087

During every congestion case, as per the proposed objective function few generators take part in rescheduling process. The PTCDF values of few buses are listed in Table 4.

Table 4. PTCDF of 75 bus system for selected buses at various cases

PTCDF			
Bus No.	Bilateral	Multilateral	Overloading
2	-0.0158	-0.0224	-0.0108
3	-0.0753	-0.1663	-0.1853
4	-0.1286	-0.1332	-0.1274
12	0.0334	0.0128	0.0228
18	-0.1209	-0.1374	-0.1251
19	-0.1127	-0.1208	-0.1296
30	-0.1380	-0.1296	-0.1465
71	-0.1475	-0.1529	-0.1448
75	-0.1440	-0.1507	-0.1388

The changes in real power generation which were observed at respective generator buses are tabulated in Table 5. The tabulated values are those obtained during bilateral transaction. This information of real power rescheduling is communicated through wireless technology to the respective generating stations by ISO.

The convergence characteristics of the proposed optimization techniques are given in figure 9. Apart from congestion mitigation, the bus voltages were also observed. BBKH algorithm serves in sustaining voltage stability of the system without exceeding the limiting values of $V_{max}=1.05$ and $V_{min}=0.95$ [18].

Table 5 Changes in real power generation for 75 bus system for bilateral transaction case

Method	ΔP_{g3}	ΔP_{g12}	ΔP_{g13}	ΔP_{g20}
Reported in [12]	0.7	-0.5	-0.37	0.1045
SOS proposed	0.65	-0.5	-0.31	00.102
BBKH proposed	0.62	-0.5	Not participating	0.1002

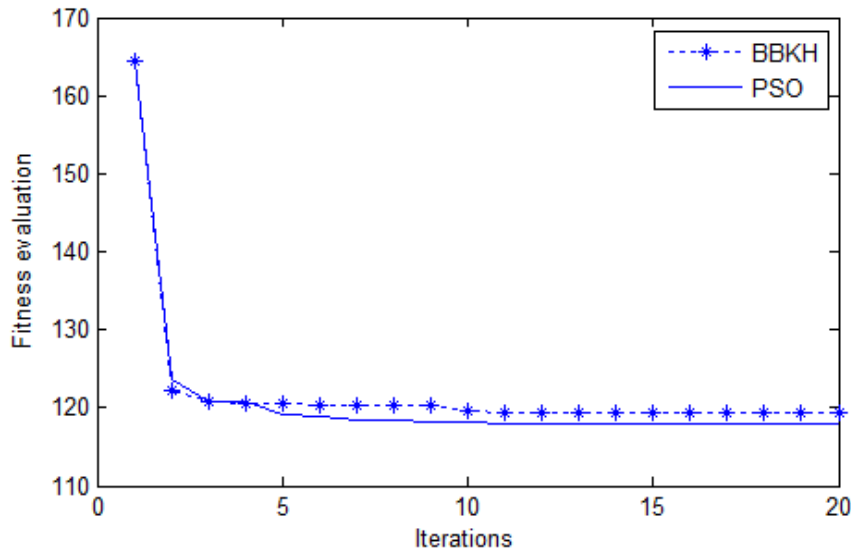


Fig 9 Convergence characteristics proposed algorithms

6.CONCLUSION

The performance of two optimization algorithms in relieving congestion in a deregulated environment is discussed in detail. It is evident from the discussion that the proposed objective suits well to manage congestion without violating the voltage stability limit and thermal limits of the line. Moreover, the losses are also reduced. Among PSO and BBKH, the superiority of the later one in solving the proposed multi-objective problem, is appreciated.

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