Journal of Intelligent & Fuzzy Systems 42 (2022) 6195–6208
DOI:10.3233/JIFS-212717
IOS Press

Congestion management in deregulated power system by series facts device using heuristic optimization algorithms

Sophia Jasmine George[a,*], Satish Kumar Ramaraju[b], Vanitha Venkataraman[c], Thenmalar Kaliannan[d], Umadevi Kumaravel[e] and M. Veerasundaram[f]
[a]*Department of EEE, Sri Krishna College of Technology, Coimbatore, Tamilnadu, India*
[b]*Department of Medical Electronics Engineering, Sengunthar College of Engineering, Namakkal, Tamilnadu, India*
[c]*Department of Electrical and Electronics Engineering, VSB College of Engineering Technical Campus, Coimbatore, Tamilnadu, India*
[d]*Department of Electrical and Electronics Engineering, Vivekanandha College of Engineering for Women, Namakkal, Tamilnadu, India*
[e]*Department of Electrical and Electronics Engineering, Sengunthar Engineering College, Namakkal, Tamilnadu, India*
[f]*Department of Electrical and Electronics Engineering, Sri Sairam Institute of Technology, Chennai, Tamilnadu, India*

AUTHOR COPY

Abstract. Conventionally in many countries, electrical power industry is organized as vertically integrated system. Under this system, large utilities are authoritative for the generation, transmission and distribution of electrical power. Such utilities are governed by the rules and regulations of the government and are forced to operate within the prescribed guidelines with minimal profit. This confirmation causes an ineffective and sluggish perspective in power industry with a lack of technical innovation, competent management and customer satisfaction. To overcome these deficiencies, power sector around the globe is getting restructured. This paper addresses an inevitable technical disputes occurring in deregulated environment i.e., transmission congestion which has an adverse effect on system security, increase in electricity pricing and line losses. Flexible AC Transmission System (FACTS) is a boon to the power sector which helps in a better and reliable power flow through the transmission lines. The problem is articulated as a multi objective function satisfying all the operational and security limits. Three heuristic algorithms namely Particle Swarm Optimization (PSO), Symbiotic Organism Search (SOS) and hybrid Quantum based PSO-Bio-geography based krill herd optimization (Q-PSOBBKH) algorithms were applied in finding solution to this complex congestion problem. To study the effectiveness of the proposed objective, IEEE 14 bus system was considered as the test system. In order to validate the proposed methodology three congestion cases i.e. bilateral transaction, multilateral transaction and overloading were imposed on the test bus system. Simulation was carried out in MATLAB.

Keywords: Deregulated power system, particle swarm optimization, symbiotic organism search algorithm, hybrid quantum based PSO, bio-geography based Krill Herd Algorithm

*Corresponding author. Sophia Jasmine George, Department of EEE, Sri Krishna College of Technology, Coimbatore, Tamilnadu 641042, India. E-mail: sophiajasmine.g@skct.edu.in.

ISSN 1064-1246/$35.00 © 2022 – IOS Press. All rights reserved.

1. Introduction

For several decades, the layout of electric power industry has been organized as Vertically Integrated Utility (VIU) in which generation, transmission and distribution of electrical power are monopolistic. These state owned utilities frame the policies and regulations as per the government and operate according to that guidelines. Also these utilities necessitate providing a reliable power to the consumer with fair returns. This convention has led to an incompetency and passiveness in the power industry with inadequate inspiration for technical innovation, fair administration and customer centre. Adding to this shortfall, the augmentation of the population has led to the increased demand for electrical power. Conducive to cater the required electrical power for the consumers, it is inevitable to enhance the existing power system or to establish a new system. As the latter is a much costlier option, the concentration has been focused towards enhancing the existing power system.

Due to various reasons, such as high demand growth, irrational tariff policies and to let the utilities function competitively and consumers to opt suppliers of electrical power, the layout of market structure slowly paved the way to a competitive environment called the deregulated power system or deregulated energy market. Deregulation offers competition among the power generating companies and provides choice to the consumers for choosing a better utility [1]. "Deregulation in power industry is a restructuring of the rules and economic incentives that governments set up to control and drive the electric power industry". Unlike other commodities, electricity cannot be stored and hence has to be transported through transmission lines so as to meet the unpredictable load. When electrical power is transmitted through transmission lines, the lines are stressed with certain technical constraints but have to be operated maintaining the reliability and security of the power system. Solution methods are being proposed by various researchers for this chaotic technical crisis. An extensive survey and an organized contribution of various researchers in providing resolution towards the congestion in transmission lines in presented in [2]. The survey deliberates from traditional approach till most prominent method i.e., rescheduling of generating units. Overload reduction due to transmission congestion is accomplished by rescheduling of real power generation by Relative Electrical Distance (RED) method [3] in which the computational time required to solve the congestion problem is found to be lesser. In optimal power flow based congestion management, benders decomposition technique [4] is adopted. One of the index used to identify congestion is Transmission Congestion Distribution Factor (TCDF) [5] in which the most sensitive generators and loads are identified using TCDF values. Sensitivity of the transmission line is another tool employed to measure congestion [6] in which line loading factor is determined to identify the overloaded lines and hence are penalized. Optimal bidding strategy based congestion management [7] is another technique in which the objective is to produce profit for both the buyers and sellers of open access power market. Available Transfer Capacity (ATC) is alternative unique metric [8] used by researchers to identify congestion in the line.

FACTS devices aid in optimal power flow in AC power transmission. Among different types of FACTS devices, Thyristor Controlled Series Controller (TCSC) offers variable impedance thereby promotes better power transmission as well as relieves congestion. The effect of TCSC in congestion management and spot prices during bilateral transaction is presented in [9]. Further the study of compensation level of TCSC at different load conditions is also accomplished. FACTS devices perform better when it is positioned at optimal location. Methods such as Priority list method [10], sensitivity based methods such as real power performance index and reduction of total system VAR power losses [11], Weighted mean method [12] are being used to choose optimal location of FACTS device. Optimization algorithms also find its extensive application in locating the position of FACTS device as well as setting the device parameters. Authors in [13, 14] presented GA based FACTS placement methodology in a deregulated environment. The proposed approach results in enhancing the stability of power system, power transfer capability of the line, voltage profile of the system with reduction in generation cost and transmission losses. Though the proposed method is efficient, the solution achieved by GA occasionally struck in local maxima.

Optimization algorithms are being adopted by researchers for congestion mitigation. Fuzzy Evolutionary Programming and GA [15], Multi-objective genetic algorithm [16], Moth flame algorithm [17], cuckoo search algorithm [18], Firefly algorithm [19], Particle Swarm Optimization (PSO) algorithm [20], Adaptive Particle Swarm Optimization Algorithm [21, 22], and dragonfly algorithm [23–25] are

AUTHOR COPY

some of the evolutionary algorithms used by various researchers to mitigate transmission congestion. A wide survey on transmission congestion has been presented [26].

As reported by Central Electricity Regulatory Commission of India, due to transmission congestion the amount of power that has been transacted is decreased by 0.92% [27] during 2018–19. Consequently, congestion charge of Rs.137.52 crore has been imposed at both the power exchanges. Hence it is inevitable to manage the transmission congestion for economic operation of the power sector and thus congestion management is a vital research problem to be solved.

In most of the earlier congestion management methods, the objective function to solve congestion is articulated as a single objective function with minimization of congestion cost or minimization of rescheduled generation cost as the objectives. Most of the congestion management methods used in the previous work focus on a specific sort of contingency such as line outage, bilateral transactions etc. It is required to have a wide analysis over the congestion or contingency cases. Although many researchers have used FACTS devices, some literatures fail to indicate the method to choose its parameters. The parameter values are to be optimized when working with real time environment. Similarly, the control parameters of optimization algorithm are chosen randomly which may affect convergence rate, computational time and efficiency of the overall system. Hence a solution methodology which rectifies all these flaws for the successful operation of the power system is required. In this paper, the problem of transmission congestion is solved using three challenging optimization algorithms PSO, SOS and hybrid QPSOBBKH.

2. Objectives of the optimization problem

Any optimization problem involves the formation of objective function. In this paper the objective function includes minimization of three parameters i.e., (i) congestion cost minimization (ii) TCSC installation cost minimization and (iii) transmission losses minimization.

2.1. Congestion cost minimization

The first objective is the congestion cost minimization i.e. congestion occurring in the transmission line is measured in terms of congestion cost. The utility companies and the customers offer their generation and demand bids respectively to ISO. The generation bids $C_{gi}(P_{gi})$ is expressed as the generator cost equation. Generally the generator cost equation is represented in terms of quadratic equation as,

$$C_{gi}\left(P_{gi}\right) = a_{gi}P_{gi}^2 + b_{gi}P_{gi} + c_{gi} \tag{1}$$

where, a_{gi}, b_{gi} and c_{gi} are the generator cost coefficients.

P_{gi} is the generated power for bidding.

The deregulated environment provides opportunity for the customers to choose their favourable utility based on the generator bids. Hence, the load requirement at the load bus varies depending on the readiness of the customer to accept and pay for the bid. Similar to the generator bid, the demand bids at any load bus i can be formulated as,

$$B_{di}\left(P_{di}\right) = a_{di}P_{di}^2 + b_{di}P_{di} + c_{di} \tag{2}$$

Where, a_{di}, b_{di} and cdi are the demand cost coefficients.

P_{di} is the power demand for bidding.

Hence,

$$f_1 = \min\left\{\sum_{i=1}^{N_G} C_{gi}\left(P_{gi}\right) - \sum_{i=1}^{N_D} B_{di}\left(P_{di}\right)\right\} \tag{3}$$

2.2. TCSC installation cost minimization

The second objective is to minimize the cost of TCSC by choosing its appropriate reactance X_{TCSC}. TCSC is a series FACTS device which offers variable reactance to the line where it is connected. In this paper, TCSC is modelled as a variable reactance [9].

The installation cost of TCSC is mathematically represented by,

$$f_2 = \min\{\frac{C_{TCSC}xS_{TCSC}x1000}{8760}\} \tag{4}$$

where,

C_{TCSC} is the cost of TCSC in \$/kVAR represented by,

$$C_{TCSC} = 0.0015\ S_{TCSC}^2 - 0.7130S_{TCSC} + 153.75 \tag{5}$$

S is the operating range of TCSC represent

$$S = X_{TCSC}x\left|I_{i,j}^{max}\right|^2 \tag{6}$$

AUTHOR COPY

2.3. Transmission losses minimization

During congestion, the power loss (Ploss) occurring in the line is more. The third objective is to minimize the transmission losses.

$$f_3 = min\left(I_{ij}^2 x X_{tline}\right) \tag{7}$$

2.4. System constraints

The objective functions given in Equations (3), (4) and (7) should satisfy the following equality and inequality constraints:

(i) Equality constraint: According to Newton Raphson (NR) load flow analysis, the equation for real power (P_{gi}) and reactive power (Q_{gi}) at generator bus and load bus is given by,

$$P_{gi} - P_{di} = \sum_{j=1}^{N_g} |V_i| \left|V_j\right| \left|Y_{ij}\right| cos\left(\delta_i - \delta_j - \theta_{ij}\right) \tag{8}$$

$$Q_{gi} - Q_{di} = \sum_{j=1}^{N_g} |V_i| \left|V_j\right| \left|Y_{ij}\right| sin\left(\delta_i - \delta_j - \theta_{ij}\right) \tag{9}$$

(ii) Inequality Constraints:

The amount of power flow after rescheduling the generators should lie within the maximum power flow limit of any line connected between buses i, and bus j (S_{ij}^{max}). So the inequality constraint is given by,

$$\left(P_{ij} + \sum_{i=1}^{N_G} PTCDF_i^k X P_i\right)^2 \leq \left(S_{ij}^{max}\right)^2 \tag{10}$$

where, k ranges between 5 % to 10%. It is the profit estimate of real power generation at i^{th} bus, and ΔP_i is the real power adjustments of generator at i^{th} bus.

(a) The real and reactive power generation of every generating unit is limited by their maximum and minimum power limit which is represented by,

$$P_{gi,min} \leq P_{gi} \leq P_{gi,max} \tag{11}$$

$$Q_{gi,min} \leq Q_{gi} \leq Q_{gi,max} \tag{12}$$

(b) The real and reactive power demand at every load is limited by their maximum and minimum power limit which is given by,

$$P_{di,min} \leq P_{di} \leq P_{di,max} \tag{13}$$

$$Q_{di,min} \leq Q_{di} \leq Q_{di,max} \tag{14}$$

(c) The voltage at any bus i (V_i) is limited by its maximum and minimum voltage limit. This is given by,

$$V_{i,min} \leq V_i \leq V_{i,max} \tag{15}$$

(d) The reactance of TCSC which is located in al line between any buses i and j (X_{TCSC}) should lie within its maximum and minimum reactance limit. The inequality constraint is given by,

$$X_{TCSC,min} \leq X_{TCSC} \leq X_{TCSC,max} \tag{16}$$

Three different congestion cases i.e., bilateral transaction, multilateral transaction, line overloading were imposed on the IEEE 14 bus system to make the line congested and hence to validate the proposed objective function.

3.. Heuristic algorithms

3.1. Particle swarm optimization (PSO)

PSO is a simple, fast and efficient stochastic optimization method proposed by Kennedy in 1985. In an N-dimensional space, each particle is deliberated to be a resolution who's conspicuous and subsidiary degree are estimated by calculating its fitness rate. The particles have the accountability to hold memory of the paramount positions they have accomplished throughout the progression of traverse in search space and share this information to the other particle. In the progression of each generation, couple of values are restructured for each particle viz. the best position (distinct best position) or fitness value it has accomplished prior named as the position best or pbest, Pi = (pi1, pi2, ...pin) and the paramount value accomplished by any other particle in the population called as global best or gbest, Gi = (gb1, gb2, ... gin). Each particle maintains, Location in the search space,

Velocity, Distinct best position. Apart from this, the swarm also maintain its global best position. Considering N dimensional space, the particles are generated arbitrarily and it possess two parameters

Locus of the particle Xi=(Xi1, Xi2, ... Xin)

Velocity of the particle, Vi=(Vi1, Vi2, ... Vin)

Based on the information about its pbest and gbest values the particles update their positions and velocities using the following Equations(17) and (18)

AUTHOR COPY

respectively.

$$V_i(t+1) = \omega * V_i(t) + C_1 * rand1 * [p_i(t) - X_i(t)] + C_2 * rand2 * \left[gb_i(t) - X_i(t)\right] \quad (17)$$

$$X_i(t+1) = X_i(t) + V_i(k+1) \quad (18)$$

Where, i is the particle index,

ω represents inertia weight. The inertia component ω, keeps the particle moving in the same direction it was originally heading. Lower values of ω speed up convergence where as higher values strengthen exploring the search space.

- rand 1 and rand 2 represents random values (0 < rand1, rand2<,2),
- C1 and C2 called as acceleration constants (0 < C1, C2<,2).

C1, the cognitive component, acts as the particle's memory, causing it to return to its individual best regions of the search space. The coefficient limits the size of the step the particle take towards its individual best pi. C2, the social component, causes the particle to move to the best regions the swarm has found so far. It limits the size of the step the particle takes toward the global best gbi.

- k represents the iteration number,
- Vi(t), velocity of the particle at time t
- Xi(t), locus or position of the particle at time t
- Pi(t), individual best solution of the particle at time t
- gbi(t), best solution of the swarm at time t.

The algorithm steps in relieving congestion is as follows:

Step 1: Prepare the line data, bus data and all the required relevant data of the bus system along with the parameters of PSO.

Step 2: Impose congestion on the bus system and run NR power flow for the given generation and load pattern.

Step 3: Generate a random set of control variables using PSO procedure for instance incremental and decremental generation shift and TCSC parameters satisfying the limits. The values obtained are enforced in the system data.

Step 4: Run NR power flow.

Step 5: Determine if the constraints are being satisfied exempting, add the penalties & find the fitness function.

Step 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.

Step 7: Output the solution of the best generation pattern, TCSC parameters along with its suitable location in the bus system and terminate the process.

3.2. Symbiotic organism search algorithm (SOS)

Based on the social living behaviour of heterogeneous organisms in ecology De-Bary in 1878 introduced the phrase "Symbiosis" which means "living together". It attributes to the affinity of couple of species or organisms which are dissimilar but mutually dependent (symbiotic) on each other with an intention of developing its robustness to survive in the ecological community. SOS algorithm has three phases namely (i) Mutualism phase- the two species are mutually benefitted (ii) Commensalism phase –one organism is benefitted while the other does not have any impact and (iii) parasitism phase- one organism is benefitted harming the other organism. The organism which are interacting arbitrarily traverse through these three phases until the termination condition is reached.

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

1. Initialize the size of the ecosystem (n) 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:

   Let Xa and Xb are the organisms which involve in mutualism phase and the updated or new organism Xaa, Xbb are computed by Equations (18), (19) and (20).

$$X_{aa} = X_a + ran(0, 1) * (X_{best} - MV * IBF_a) \quad (19)$$

$$X_{bb} = X_b + ran(0, 1) * (X_{best} - MV * IBF_b) \quad (20)$$

$$MV = \frac{X_a + X_b}{2} \quad (21)$$

In which, ran (0,1) is a vector of random numbers, MV is the mutual vector. It represents the

AUTHOR COPY

affiliation between organisms Xa and Xb, X_{best} is the utmost degree of flexibility. In case of improved SOS, benefit factors are calculated from the parameter values obtained from the algorithm itself.

$$IBF_a = \frac{F(X_a)}{F(X_{best})}; F(X_{best}) \neq 0 \quad (22)$$

$$IBF_b = \frac{F(X_b)}{F(X_{best})}; F(X_{best}) \neq 0 \quad (23)$$

5. Commensalism Phase:
   Xa be the organism which is benefitted as it traverse through commensalism phase. The updated value Xaa is given by,

$$X_{aa} = X_a + ran(-1, 1) * (X_{best} - X_b) \quad (24)$$

   In which, (Xbest -Xb) signifies the favorable benefit provided by Xb to assist Xa developing its degree of existence in the ecology.
6. Parasitism phase:
   The best illustration to comprehend the parasitism phase is the affiliation of anopheles mosquito on human being. The pest cultivates inside the human body while declining its host with malarial infection. Correspondingly the organism Xa turns into a parasite or pest and attempts to substitute the arbitrarily choose organism Xb by creating a deceptive parasite in search space called as "parasite-vector". It is the vector involves in replacing Xb in the ecology. On the course of fitness evaluation the parasite vector or the organism whichever has more fitness value, gains more invulnerability and hold its position in the ecology while the other vanishes. Every organism in the search space undergo all the three phases and the best individual survives until the parasitism phase and remains as the fittest organism or the solution.

3.3. Proposed hybrid quantum behaved PSO and biogeography based krill herd (QPSOBBKH) optimization algorithm

Biogeography based Krill herd (BBKH) is one of the novel search based heuristic optimization algorithm recommended for continuous optimization problems. Krill (KH) method and biogeography based optimization (BBO) method was proposed by Gai-Ge Wang and Simon in 1998 respectively. The objective function endorsed in krill herd method is based on the least distance of krill from its food and the maximal herd density. A modification in PSO in order to overcome one of the disadvantages of PSO that it does not promise for a global convergence [28]. The Q-PSO dominate PSO with its wide search ability and it is a highly potent algorithm for solving complex problems. An attempt has been made to combine the benefits of Q-PSO and BBKH as hybrid QPSOBBKH to solve the congestion prevailing in the transmission line during any transaction and overloading case. The Q-PSOBBKH algorithm in solving congestion management is as follows and the flow chart is given in Fig. 1.

Step 1: Input the line, bus data's of the given system

Step 2: Initialization phase: Initialize the generation count $g = 1$, random population of krill (p), Vf, Dmax, Nmax, δmax and Pmod, number of krills, np. Similarly initialize the PSO parameters such as population size.

Step 3: Impose congestion in the considered bus system and run NR load flow program for the specified generation and load pattern.

Step 4: Evaluation phase: Every individual in the population are evaluated for its fitness.

Step 5: Partition phase: The total population (TP) is randomly separated into two equal halves (TP/2).

Step 6: BBKH process: For TP/2 population, positions are updated for the individuals adopting the three motions given by the equations

$$\frac{dx_m}{dt} = N_m + F_m + D_m \quad (25)$$

Where, Nm is the movement of krill influenced by other krills,

Fm is the foraging movement,

Dm is the diffusion movement.

$$N_m^{new} = N_{max}\alpha_m + \omega_n N_m^{old} \quad (26)$$

Where, αm is the direction in which it advances

Nmax is the maximum speed of the krill,

ωn the inertia weight

Nmold the previous motion of the krill

$$F_m = V_f\left(\beta_m^{food} + \beta_m^{best}\right) + \omega_f F_m^{old} \quad (27)$$

Where, Vf represents the foraging speed,

ωf the inertia weight,

Fmold the previous foraging value.

Include crossover and mutation components to better tune the position of the krill. Evaluate the fitness

AUTHOR COPY

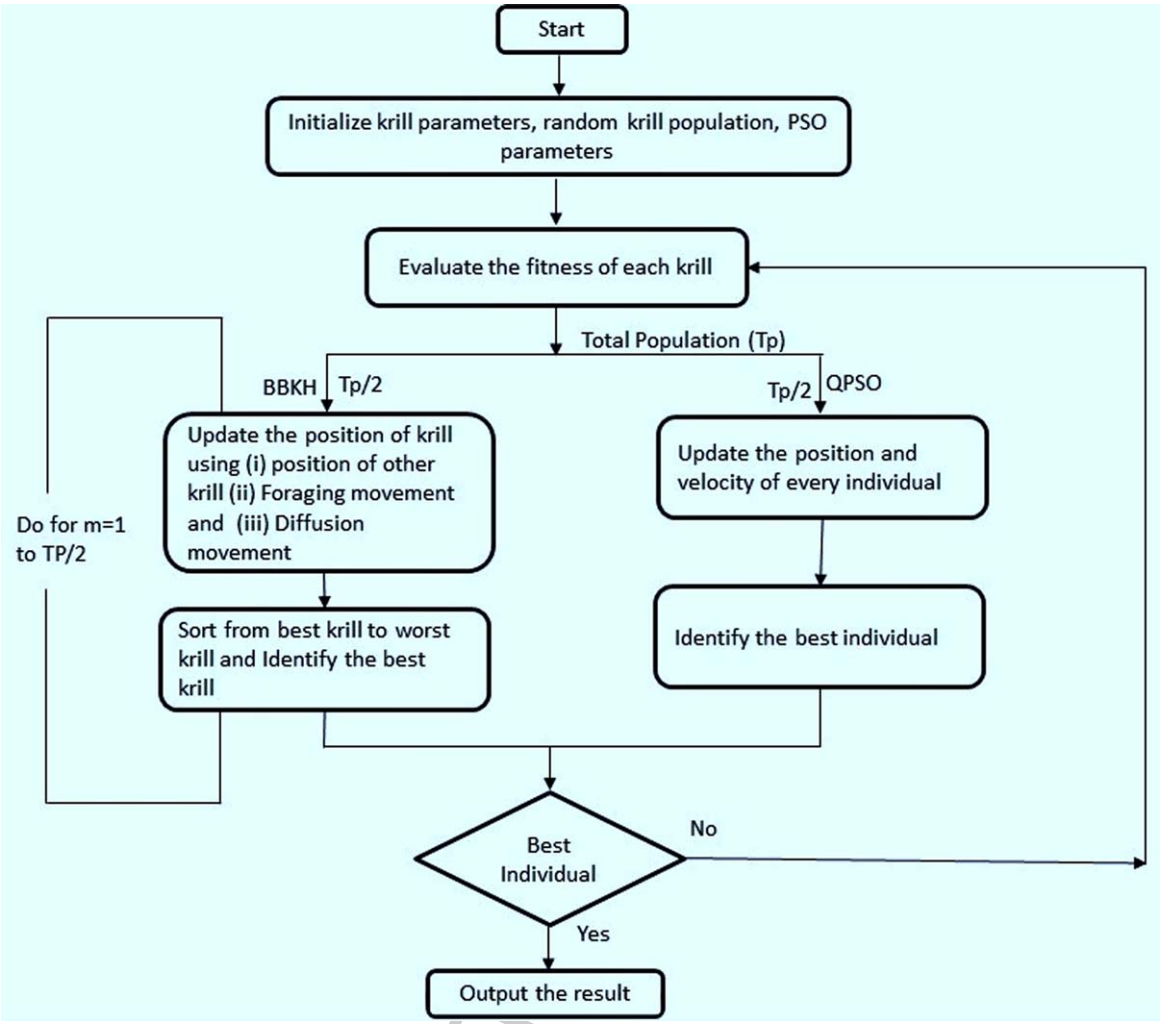


Fig. 1. Flow chart of QPSOBBKH algorithm.

of each krill and sort from best krill to worst krill. Replace the best krill in the position of worst krill. Sort the krill and identify the best krill in current generation.

The steps to be followed are depicted as follows,

For $m = 1$ to TP/2 (all krills in halved population) do

adopt three motions for every krill

update positions of each krill

End.

Step 7: Q-PSO Process:

For the remaining TP/2 population, as per the Q-PSO method, update the position of every individual a given in equation.

$$X_m(l+1) = p_m(l) \pm \alpha \left| C(l) - X_m(l) \right| \ln \frac{1}{u} \quad (28)$$

$$p_m(l) = \varphi P_m(l) + (1-\varphi) P_g(l) \quad (29)$$

Where,

p_m is a local attractor and m is the particle which is assumed to move in a hyper rectangle with Pm and Pg as its diagonals.

α is the contraction-expansion co-efficient.

m is the particle (1,2,. . . . . .M)

l is the iteration number (1,2,. . . . . .lmax)

u is a random number between 0 and 1.

C(l) is the best position and is given by equation 30 & 31

$$C(l) = (C_1(l), C_2(l), \ldots\ldots\ldots\ldots, C_N(l)) \quad (30)$$

Table 1
PSO parameters

Parameter	Value
Inertia	0.3
Damping ratio	0.95
Particle size	20
Maximum iteration	20
C1	2
C2	2

Table 2
SOS parameters

Parameter	Value
Ecosize, *n*	10
Max iteration	40

$$C(l) = \left(\frac{1}{M} \sum_{m=1}^{M} P_{m1}(l), \frac{1}{M} \sum_{m=1}^{M} P_{m2}(l) \right.$$
$$\left. \ldots\ldots\ldots\ldots \frac{1}{M} \sum_{m=1}^{M} P_{MN}(l) \right) \quad (31)$$

The steps to be followed are as follows, For all particles in population TP/2 do

Calculate Pm (l) and Pg(l)
Find the mean best position C(l)
Find p(l)
Update the position Xm($l+1$)
End

Step 8: Combination Phase: After the populations are generated in this manner, the two population are combined.

Step 9: The fitness of all the individuals is found out and the best individual is identified as the best solution.

Step 10: If the stopping criterion has reached, output the best individual and Q-PSO algorithm is terminated. Otherwise go to step 4.

4. Results and discussion

The effectiveness of the objective function is validated using the three algorithms as discussed in previous sections and also by imposing three congestion cases (i) bilateral transaction (ii) multilateral transaction and (iii) overloading on standard IEEE 14 bus system. The algorithm parameters are provided in Tables 1, 2 and 3.

Table 3
QPSOBBKH parameters

Parameter	Value
number of krills, np	20
Maximum iteration, max $_{iteration}$	150
foraging speed, V_f	0.2
maximum diffusion speed, D_{max}	0.005
maximum speed of the krill, N_{max}	0.01
Inertia weight (foraging speed),ω_f	0.3
Inertia weight, ω_n	0.3
emigration rate, μ	0.3

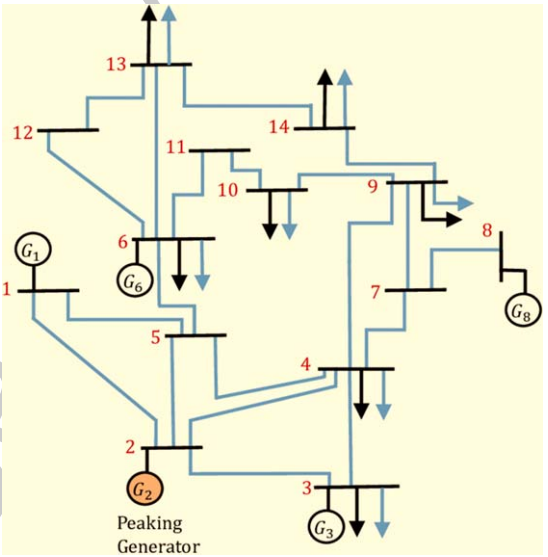


Fig. 2. Single line diagram of IEEE 14 bus system.

Table 4
TCSC parameters setting during bilateral transaction

TCSC Parameters	Bilateral		
	PSO	SOS	QPSOBBKH
Optimal location	Line. No. 7	Line. No. 7	Line. No. 7
Compensation (KTCSC)	–0.5 p.u.	–0.5 p.u.	–0.45 p.u.
Mode of operation	Capacitive	Capacitive	Capacitive
Reactance (XTCSC)	–0.1102 p.u.	–0.1010 p.u.	–0.1010 p.u.

4.1. IEEE 14 bus system

IEEE 14 bus system has three generators, fourteen buses, twenty transmission lines and eleven loads with a base load demand of 259 MW as shown in Figure 2. The algorithm suggests line no.7 to be the optimal location to place TCSC as well as the parameter setting is also optimized as given in Table 4. The line data's are provided in Table 5.

AUTHOR

Table 5
Line data-IEEE 14 bus system

Line number	From bus	To bus	Line impedance (*p.u.*)		Half line charging Susceptance (*p.u.*)	MVA rating
			Resistance	Reactance		
1	1	2	0.01938	0.05917	0.02640	120
2	1	5	0.05403	0.22304	0.02190	65
3	2	3	0.04699	0.19797	0.01870	36
4	2	4	0.05811	0.17632	0.02460	65
5	2	5	0.05695	0.17388	0.01700	50
6	3	4	0.06701	0.17103	0.01730	65
7	4	5	0.01335	0.04211	0.00640	45
8	4	7	0	0.20912	0	55
9	4	9	0	0.55618	0	32
10	5	6	0	0.25202	0	45
11	6	11	0.09498	0.1989	0	18
12	6	12	0.12291	0.25581	0	32
13	6	13	0.06615	0.13027	0	32
14	7	8	0	0.17615	0	32
15	7	9	0	0.11001	0	32
16	9	10	0.03181	0.0845	0	32
17	9	14	0.12711	0.27038	0	32
18	10	11	0.08205	0.19207	0	12
19	12	13	0.22092	0.19988	0	12
20	13	14	0.17093	0.34802	0	12

Table 6
Performance comparison of algorithms – Bilateral transaction

Line No.	Line flows in MVA				
	Line flows limit	Without optimization	PSO algorithm	SOS algorithm	Q-PSOBBKH algorithm
1	120	128	119.45	119.02	118.58
2	65	75.6	66	64.68	64.82
4	65	82.3	65.01	64.12	65
5	50	54	50.11	50	49.57
6	63	64	62.37	60.4	60.54

Table 7
Performance comparison of algorithms – multilateral transaction

Line No.	Line flows in MVA				
	Line flows limit	Without optimization	PSO algorithm	SOS algorithm	Q-PSOBBKH algorithm
2	65	70.28	64.5	64.67	64.88
3	36	38.02	36	35.78	34.21
4	65	66.3	64.08	63.25	64.37
5	50	53.55	50.01	47.40	49.40
6	63	72.10	62.88	61.08	62.91

AUTHOR COPY

Case (i)

A bilateral transaction of 50 MW between a generator bus and a load bus make some of the lines congested. Here a similar transaction is carried out between buses 2 and 6. The congested lines, its line flow limits and the optimized values are given in Table 6. During transaction, the following lines are severely congested and the performance of the algorithm in congestion management is also furnished.

Case (ii)

A multilateral transaction of 50 MW is carried out between bus 2 and buses 4, 5 and hence congestion is imposed on few lines. Few of the congested lines, their line flow limits and the optimized line flows are given in Table 7. The TCSC parameter setting and the location are given in Table 8.

Case (iii)

In order to impose overloading and hence congestion, the total demand is increased by 10%. Table 9

Table 8
TCSC Parameters setting during multilateral transaction

TCSC Parameters	Multilateral Transaction		
	PSO	SOS	QPSOBBKH
Optimal location	Line. No. 6	Line. No. 6	Line. No. 7
Compensation (KTCSC)	–0.5 p.u.	–0.47 p.u.	–0.413 p.u.
Mode of operation	Capacitive	Capacitive	Capacitive
Reactance (X_{TCSC})	–0.11 p.u.	–0.1052 p.u.	–0.1052 p.u.

Table 9
Details of congested lines due to overloading

Line No.	Line flows in MVA				
	Line flows limit	Without optimization	PSO algorithm	SOS algorithm	Q-PSOBBKH BBKH algorithm
3	36	41.05	35.22	34.5	35.27
7	45	48.29	44.65	44	43.51
8	55	60.02	55.00	54.67	54.51
11	18	19.3	16.25	18	17.85
13	32	35.96	30.08	30.56	30.43
16	32	38.24	31.79	30.94	31.5
18	12	15.55	11	11.24	11.07

Table 10
TCSC Parameters setting during overloading

TCSC Parameters	Overloading		
	PSO	SOS	QPSOBBKH
Optimal location	Line. No. 7	Line. No. 7	Line. No. 7
Compensation (K_{TCSC})	–0.5 p.u.	–0.45 p.u.	–0.55 p.u.
Mode of operation	Capacitive	Capacitive	Capacitive
Reactance (X_{TCSC})	–0.1102 p.u.	–0.10 p.u.	–0.10 p.u.

depicts some of the most severely congested lines due to overloading. The parameter setting of TCSC and its optimal location in the bus system is given in Table 10. The optimal location to place TCSC can be obtained from the sensitivity index (aij) [29]. The sensitivity index of few lines is shown in Table 11. The line with most positive index value is chosen as the best location to place TCSC.

If the congestion is not relieved with TCSC, the algorithm recommends for generator rescheduling. The entire bus system is divided into three zones such that the cluster of buses and loads are grouped as a zone. Zones are formed based on the values of PTCDF. It is the factor which indicates the amount of real power change in a line due to the injection of real power at any bus. The PTCDF value indicates the amount of real power that could be transmitted through a transmission line. Based on the value of PTCDF, the generators participating in rescheduling of generation are identified and hence they take part in rescheduling. Other than the objective function minimization, the proposed objective helps to maintain the voltage profile of the entire system thereby maintaining the voltage stability of the system with in its prescribed limit. The convergence characteristics of the three algorithm is given below in Fig. 3(a). The

Table 11
Sensitivity index of IEEE 14 bus system for chosen lines at various cases

Bilateral		Multilateral		Overloading	
Line no. (From bus, i-To bus, j)	aij	Line no. (From bus, i-To bus, j)	aij	Line no. (From i-To bus, j)	aij
2 (1-5)	–0.00653	3 (2-3)	–0.00583	2 (1-5)	–0.00755
7 (4-5)	–0.00156	5 (2-5)	–0.00238	7 (4-5)	–0.00024
9 (4-9)	–0.00854	6 (3-4)	–0.00096	11 (6-11)	–0.00093
12 (6-12)	–0.05024	13 (6-13)	–0.00158	13 (6-13)	–0.00246

AUTHOR COPY

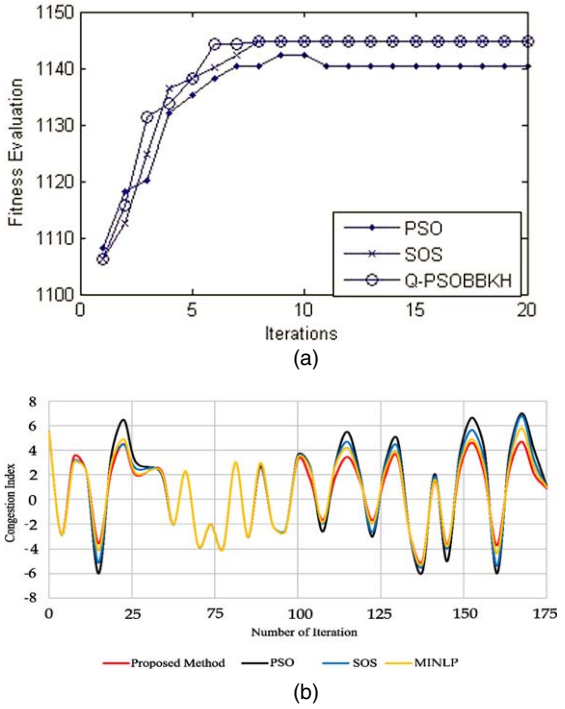


Fig. 3. (a) Convergence characteristics PSO, SOS and QPSOBBK. (b) Congestion index with proposed algorithm using number of iteration.

finite time with fast convergence capability of proposed algorithm shown in Fig. 3(b). The per unit voltage values at every nodes of IEEE 14 bus system is given in Figs. 4–6. It is evident that, irrespective of the congestion cases, the voltage at every bus is within the prescribed limit thereby the voltage stability of the given bus system is maintained within the prescribed limit. The comparison of the proposed approach against the work done is furnished in Tables 12 and 13. It is to be noted that magnitude of voltage is maintained at 1 p.u. except at buses 1 and 8 with SOS algorithm. From the characteristics it is evident that QPSOBBKH converges much faster than PSO and SOS algorithm and hence proves its efficacy [30–33].

5. Conclusion

The modernization of power sector from vertically integrated utility to deregulated power market has led to economic and technical challenges. Congestion management is one of the most significant issue to be resolved with utmost priority as it could invoke further outages if unattended. In this paper, a rational solution to solve this critical issue was presented. A multi-objective problem is formulated in view of minimizing congestion cost, installation cost of TCSC and transmission losses. Three heuristic algorithms were used to solve the multi-objective problem and their efficacy in solving the objective function was furnished with various test cases imposed on IEEE 14 bus system. The results obtained from the test cases illustrate that the performance of QPSOBBKH is superior in relieving congestion which is measured by reduction in congestion cost, installation cost of TCSC and transmission losses. Moreover the voltage

AUTHOR COPY

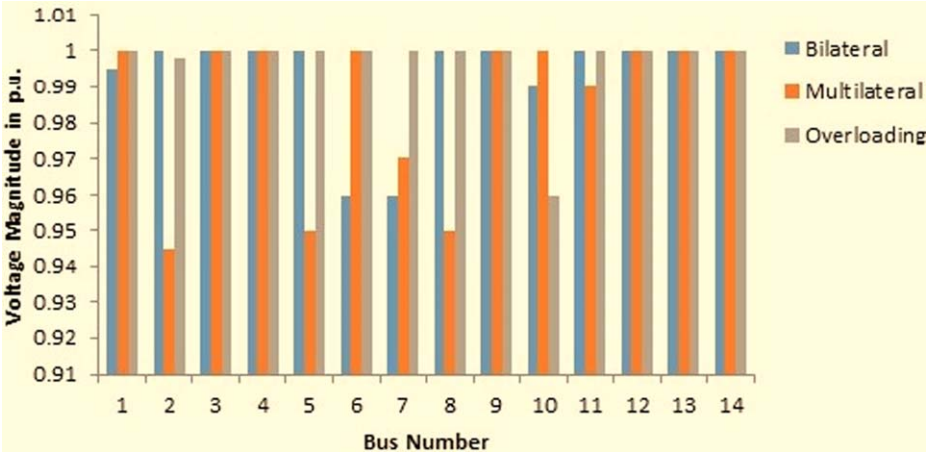


Fig. 4. Voltage magnitude at each bus (PSO).

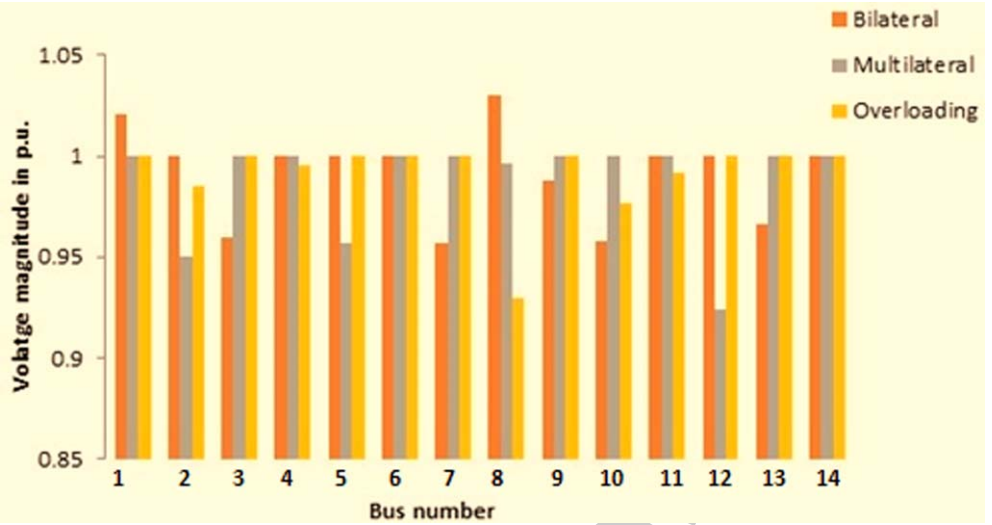


Fig. 5. Voltage magnitude at each bus (SOS).

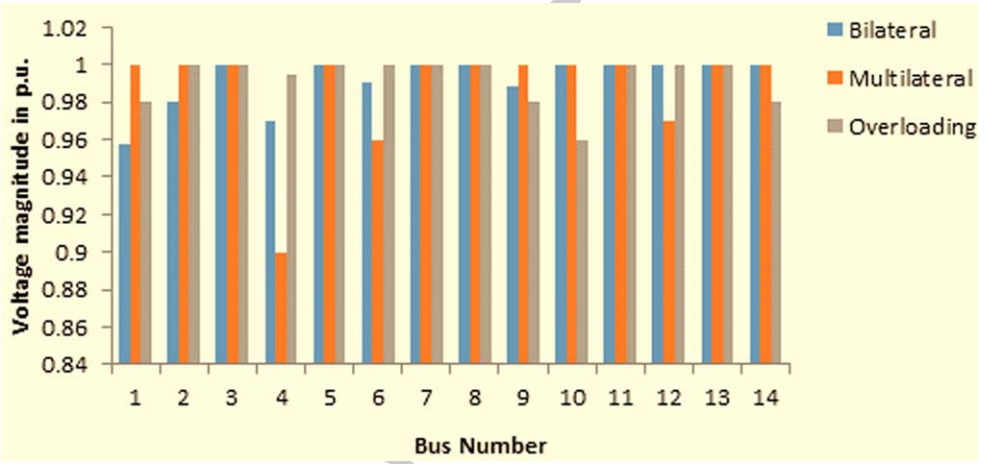


Fig. 6. Voltage magnitude at each bus (QPSOBBKH).

Table 12
Comparison of Installation cost of TCSC

Sl. no.	Comparison of approaches	TCSC Installation cost in $/hr.
1.	APSPI [7]	**0.0911**
	PSO [14]	0.088(bilateral)
		0.0907(multilateral)
		0.0820(overloading)
2.	SOS [20]	0.090(bilateral)
		0.0875(multilateral)
		0.0882(overloading)
	Q-PSOBBKH	**0.0910(bilateral)**
	Proposed work	**0.0897(multilateral)**
		0.0886(overloading)

Table 13
Comparison of congestion cost with other approaches – IEEE 14 bus System

S.No.	Approaches	Congestion Cost ($/hr)
1.	OPF [9]	2065
	PSO [18]	2004.5(bilateral)
		1995.7(multilateral)
		2043.36 (overloading)
2.	SOS [20]	2001.82(bilateral)
		1992.67(multilateral)
		2040.18 (overloading)
	Q-PSOBBKH	**1904.5(bilateral)**
	(Proposed work)	**1986.7(multilateral)**
		2024.82 (overloading)

profile of the system is well maintained within the prescribed limit.

References

[1] L. Phillipson and H.L. Willis, Understanding Electric Utilities and Deregulation, Marcel Dekker Inc., New York, 1999.

[2] Anusha Pillay, S. Prabhakar Karthikeyan and D.P. Kothari, Congestion management in power systems-a review, *Journal of Electric Power Systems Research* **70** (2015), 83–90.

[3] G. Yesurathnam, and D. Thukaram, "Congestion management in open access based on relative electrical distance using voltage stability criteria, *Journal of Electric Power Systems Research* **77** (2007), 1608–1618.

[4] Y. Xiao, P. Wang and L. Goel, Congestion management in hybrid power markets, *Journal of Electric Power Systems Research* **79** (2009), 1416–1423.

[5] R. Bansal and S.K. Gupta, TCDFs based congestion management using TCSC, *Proceedings of the fifth Power India Conference*, 2012. DOI: 10.1109/PowerI.2012.6479528.

[6] M. Tauseef Khan and A. Shahzad Siddiqui, Congestion management in deregulated power system using FACTS device, *International Journal of System Assurance Engineering and Management* **8** (2017), 1–7.

[7] S. Gope, S. Dawn, A.K. Goswami and P.K. Tiwari, Moth flame optimization based optimal bidding strategy under transmission congestion in deregulated power market, *Proceedings of the Region 10 Conference (TENCON)* (2016), 617–622.

[8] K. Majumdar, P. Kumar Roy and S. Banerjee, Available transfer capacity evaluation through evolutionary algorithms, *Proceedings of the International Conference on Microelectronics, Computing and Communications*, 2016. Doi:10.1109/MicroCom.2016.7522469.

[9] N. Acharya and N. Mithulananthan, Locating series FACTS devices for congestion management in deregulated electricity markets, *Journal of Electric Power Systems Research* **77** (2007), 352–360.

[10] N. Acharya and N. Mithulanathan, Influence of TCSC on congestion and spot price in electricity market with bilateral contract, *Journal of Electric Power Systems Research* **77** (2007), 1010–1018.

[11] H. Besharat and S.A. Taher, Congestion management by determining optimal location of TCSC in deregulated power systems, *Journal of Electric Power and Energy Systems* **30** (2008), 563–568.

[12] A. Shahzad Siddiqui, M. Tauseef Khan and F. Iqbal, Determination of optimal location of TCSC and STATCOM for congestion management in deregulated power system, *International Journal of System Assurance Engineering and Management* **8** (2017), 101–117.

[13] A.K.M. Rezwanur Rahman, S. Alam Md, ZakirHossain Md and Shahjahan Md, Localization FACTS devices for optimal power flow using genetic algorithm, *Proceedings of the international conference on Electrical Information and Communication Technology (EICT)*, 2014. DOI: 10.1109/EICT.2014.6777889.

[14] P. Kumar and R. Pukale, Optimal power flow using PSO, *Journal of computational intelligence indata mining* **1** (2014), 109–121.

[15] K. Vijayakumar, Multi-objective optimization methods for congestion management in deregulated power systems, *Journal of Electrical and Computer Engineering* **12** (2012), 1–8.

[16] S. Sivakumar, R. Narmatha Banu and D. Devaraj, Multi objective genetic algorithm for congestion management in deregulated power system, *Proceedings of the International Conference on Computational Intelligence and Computing Research*, 2013. DOI: 10.1109/ICCIC.2013.6724208.

[17] J. Drusila Nesamalar, P. Venkatesh and S. Charles Raj, Energy management by generator rescheduling in congestive deregulated power system, *Journal of Applied Energy* **171** (2016), 357–371.

[18] D. Fathema Farzana and K. Mahadevan, Performance comparison using firefly and PSO algorithms on congestion management of deregulated power market involving renewable energy sources, *Soft Computing* **24** (2020), 1473–1482.

[19] Sarwar Md and A. Shahzad Siddiqui, An efficient particle swarm optimizer for congestion management in deregulated electricity market, *Journal of Electrical Systems and Information Technology* **2** (2015), 269–282.

[20] G. Sophia Jasmine and P. Vijayakumar, Congestion Management in Deregulated Power System Using Heuristic Search Algorithms Incorporating Wireless Technology, *International Journal of Wireless Personal Communication* **94** (2017), 2665–2680.

[21] J. Sun, B. Feng and W.B. Xu, Particle swarm optimization with particles having quantum behavior, *Proceedings of the Congress Evolutionary Computational Conference*, pp 325–331, 2004.

[22] I. Batra and S. Ghosh, A Novel Approach of Congestion Management in Deregulated Power System Using an Advanced and Intelligently Trained Twin Extremity Chaotic Map Adaptive Particle Swarm Optimization Algorithm,

AUTHOR COPY

Arabian Journal for Science and Engineering **44** (2019), 6861–6886.

[23] http://www.cercind.gov.in/2019/market_monitoring/Annual%20Report%202018-19.pdf

[24] G.B. Shrestha and W. Feng, Effects of series compensation on spot price power markets, *Journal of Electrical Power and Energy Systems* **27** (2005), 428–436.

[25] C. Saravanan and P. Anbalagan, Multi objective dragonfly algorithm for congestion management in deregulated power systems, *Journal of Ambient Intelligence and Humanized Computing* **12** (2021), 7519–7528.

[26] M. Mohan Gajjala and A. Ahmad, A survey on recent advances in transmission congestion management, *International Review of Applied Sciences and Engineering* **13**(1) (2021). https://doi.org/10.1556/1848.2021.00286

[27] J.R. Albert and A.A. Stonier, Design and development of symmetrical super-lift DC–AC converter using firefly algorithm for solar-photovoltaic applications, *IET Circuits Devices Syst* **14**(3) (2020), 261–269. https://doi.org/10.1049/iet-cds.2018.5292

[28] Murugesan, Malathi et al., A Hybrid Deep Learning Model for Effective Segmentation and Classification of Lung Nodules from CT Images, 1 Jan. 2021, 1–13. DOI: 10.3233/JIFS-212189.

[29] Johny Renoald Albert and Dishore Shunmugham Vanaja, Solar Energy Assessment in Various Regions of Indian Sub-continent, Solar Cells – Theory, *Materials and Recent Advances, IntechOpen*, (December 10th 2020). DOI: 10.5772/intechopen.95118.

[30] T. Kaliannan, J.R. Albert, D. Muhamadha Begam and P. Madhumathi, Power Quality Improvement in Modular Multilevel Inverter Using for Different Multicarrier PWM, *European Journal of Electrical Engineering and Computer Science* **5**(02) (2021), 19–27. DOI: http://dx.doi.org/10.24018/ejece.2021.5.2.315

[31] M. Dhivya and A.J. Renoald, Fuzzy Grammar Based Hybrid Split-Capacitors and Split Inductors Applied In Positive Output Luo-Converters, *International Journal of Scientific Research in Science, Engineering and Technology* (3) (2017), 327–332.

[32] A. Johny Renoald, V. Hemalatha, R. Punitha, M. Sasikala and M. Sasikala, Solar Roadways-The Future Rebuilding Infrastructure and Economy, *International Journal of Electrical and Electronics Research* **4**(2), (2016), 14–19.

[33] K. Santhiya, M. Devimuppudathi, D. Santhosh Kumar and A. Johny Renold, Real Time Speed Control of Three Phase Induction Motor by Using Lab View with Fuzzy Logic, *Journal on Science Engineering and Technology* **5**(2) (2018), 21–27. http://jset.sasapublications.com/wp-content/uploads/2018/04/1841019.pdf

AUTHOR COPY