Multi Area Power Dispatch using Black Widow Optimization Algorithm

G. Girishkumar[1], S. Ganesan[2], N. Jayakumar[3], S. Subramanian[4]

[1]Lecturer (Deputed from Annamalai University), Department of EEE, Government Polytechnic College, Keelapaluvur, Ariyalur - 621707, Tamil Nadu, India
[2]Associate Professor, Department of EEE, Government College of Engineering, Salem 636011, Tamil Nadu, India
[3]Lecturer (Deputed from Annamalai University), Department of EEE, Government Polytechnic College, Uthangarai - 635207, Tamil Nadu, India
[4]Professor and Head, Department of Electrical Engineering, Annamalai University, Annamalai Nagar - 608002, Tamil Nadu, India

Abstract
Sophisticated automation-based electronics world, more electrical and electronic devices are being used by people from different regions across the universe. Different manufacturers and vendors develop and market a wide variety of power generation and utilization devices under different operating parameters and conditions. People use a variety of appliances which use electrical energy as power source. These appliances or gadgets utilize the generated energy in different ratios. Night time the utilization will be less when compared with day time utilization of power. In industrial areas especially mechanical industries or Heavy machinery usage regions power utilization will be a diverse at different time intervals and it vary dynamically. This always causes a fluctuation in the grid lines because of the random and intermittent use of these apparatus while the power generating apparatus is made to operate to provide a steady output. Hence it necessitates designing and developing a method to optimize the power generated and the power utilized. Lot of methodologies has been proposed in the recent years for effective optimization and economical load dispatch. One such technique based on intelligent and evolutionary based is Black Widow Optimization BWO. To enhance the optimization level BWO is hybridized. In this research BWO based optimize the load for multi area is proposed to optimize the cost function. A three type of system was compared for economic loads of 16, 40, and 120 units. In this research work, BWO is used to improve the convergence rate and is proven statistically best in comparison to other algorithms such as HSLSO, CGBABC, SFS, ISFS. Also, BWO algorithm best optimize the cost parameter so that dynamically the load and the cost can be controlled simultaneously and hence effectively the generated power is maximum utilized at different time intervals with different load capacity in different regions of utilization.
Keywords:
Economic load dispatch, single objective multi area BWO, Optimization, Algorithm

1. Introduction

The electricity is one of the most common forms of energy that is being preferred by all parts of the people in the earth. For the efficient use, it has to be effectively transferred from the generating station point to the consumer load point. The electric power transmission from the generating or source station to the consumer end point requires so many infrastructures and for which the money has to be spent. This transmission and distribution charges is loaded to the consumers via the electricity power consumption charges or tariff. There should be some techniques to reduce these charges or cost. The cost has to be reduced somehow mostly from the transmission side to the consumer end via the distribution stages. There are many factors to be considered like single area, multi area, consumer consumption duration, peak load time, etc. The unsteady variation of these factors with respect to time results in the increase of production cost, transmission loss, overloading of the generating units. Hence there is a need for a plan to optimize at the least any one of above mentioned single objective or multi-objective parameters. For this the optimization method gives a good hand in the economic dispatching of the electrical power.

There are many optimization methods in the economic power dispatching areas. Of the above optimization methods, the Particle Swarm Optimization (PSO) method occupies the mighty space in comparison with all the other algorithms summing up to attain this space. There other methods include Artificial Neural Network (ANN), Genetic Algorithm (GA), Whale Optimization Algorithm (WOA), Fuzzy Logic, etc.

This Research work has been partitioned into many stages. Various optimization algorithms have been referred with respect to the literature in section 2 and the problem has been identified. Section 3 deals with the proposed method explanation pertaining to Black Widow Optimization. The results and its explanation are provided in Section 4 while the last section 5 gives the conclusion and future scope of this economic load dispatch for single objective multi-area factor.

Manuscript received October 5, 2022
Manuscript revised October 20, 2022
https://doi.org/10.22937/IJCSNS.2022.22.10.16

2. LITERATURE SURVEY

The literature has more works related to Particle Swarm Optimization (PSO) algorithm compared with the various other optimization methods. After PSO in the recent years many works have been optimized using the bio-inspired Whale Optimization Algorithm where the technique is based on the hunting nature of the whales to achieve the target. In the recent years the Whale Optimization Algorithm (WOA) was used for the optimization process particularly in the economic load dispatch areas for optimizing the fuel cost as well as the emission [1]. More related works have been made the comparison of various algorithms on the literature [4], [16], [22].

Adriane B. S. Serapiao (2013) [9] used Cuckoo Search Algorithm(CSA) for the economic load dispatch and optimized using simulation and the obtained results are contrasted with the other six other swarm intelligence algorithms namely the Particle Swarm Optimization, Shuffled Frog Leaping Algorithm (SFLA), Bacterial Foraging Optimization (BFO), Artificial Bee Colony (ABC), Harmony Search (HS) and Firefly Algorithm (FA). The work was done for three and six generating units and the parameters like best & worst cost, standard deviation (SD), generator constraints, transmission loss and output power respectively. Though the result was not an innovative one, the comparison among the swarm intelligence algorithm and this CSA concluded that this algorithm can be utilized to solve complex non-smooth optimization problems related in the field of operation of power systems.

Rana Al-Nahhal et al. (2019) [5] made an approach on PSO algorithm by considering the effect of the presence of wind energy on a hourly basis concentrating on the convergence rate.R.Vijay (2012) [8] performed the optimization process of the load dispatch using the Bacterial Foraging Optimization (BFO) for a three and 13 generating system with 850MW and 1800 MW capacities respectively and compared the simulated results with the Genetic Algorithm(GA) and PSO algorithm and proved that the convergence rate was better for two cases. Hari Mohan Dubey et al. (2013) [7] proposed the work by implementing a hybrid PSOGSA algorithm by combining the capabilities of GSA and PSO for solving the economic dispatch problem. This hybrid PSOGSA approach has been tested on four standard different test systems and finally it gave a best convergence rate compared to other two algorithms.

Abdelaziz et al. (2016) [6] utilized the Flower Pollination Algorithm (FPA) for the combined work on the cost as well as the fuel emission for the economic dispatch in the power systems. They compared their work along with six other standard algorithms for a six various generating systems with different units for the objective parameter of fuel cost and its emission.

Adarshvijayan Pillai et al. (2017) [3] proposed a method using whale optimization algorithm for a single area consisting of 6 generating units. The worked compared CSA, PSO, FA and FPA algorithm along with the WOA method and proved that WOA was better to a certain extent in the parameters of power loss, generating cost as well as the computational time for the algorithm.

Fatma Alzahra Mohamed et al. (2018) [2] proposed a stochastic Whale Optimization Algorithm (SWO). The work was compared with various standard algorithms like ALO, DA, ABC, WO, and GWO. Here by applying the mutation and cross over parameters the performance of the whale optimization algorithm was improved in the parameter of the fuel cost.

J.Lin and Z.J.Whang (2019) [10] demonstrated an Improved Stochastic Fractal Search (ISFS) algorithm for Multi-area economic power dispatch problems and evaluated the robustness of the ISFS algorithm on many generating units in the range of 16-120 . The results were computed and compared with the other new algorithms like Hybridizing Sum-Local Search Optimizer (HSLSO) [11], Chaotic Global Best Artificial Bee Colony (CGBABC) [12] and Stochastic Fractal Search (SFS) [13].

Nagarajan Karthik et al. (2018) [20] developed an Interior Search Algorithm (ISA) for the application on a 3 unit, 10 unit, 20 unit, and 40 unit generating test systems. The simulation was done to achieve faster convergence, accuracy and the fuel cost.

Stochastic fractal search (SFS) [26] is an effective improved stochastic fractal search (ISFS) algorithm is presented to solve the MAED problem. In ISFS, the diversity of initial population is increased through opposition-based learning (OBL) and new populations during the evolutionary process are also generated with OBL method[36]. A hybrid diffusion process combined with DE-based local search strategy is employed to enhance the exploitation ability [31, 32]. Besides, a novel repair-based penalty approach is developed to cope with equality constraints of the MAED problem. The effectiveness and robustness of the proposed ISFS scheme has been verified by the simulations conducted on three different test systems

The main objective of the proposed work is to minimize the fuel cost by adopting the novel optimization method thereby to reduce the overall generation cost and finally provide the electricity consumption cost to a lower most value from the consumer point of view. To provide a solution for the above identified issue, in this research work a Single objective Multi area based economic load distribution procedure is optimized using the Black Widow optimization.

3. PROPOSED METHOD

The conventional optimization procedures fail when the optimization function is non differentiable one or if it has more non linearity or it is discontinuous one. To solve these issues the focus is shifted towards Evolutionary computation-based procedures or natural selection-based techniques. The Stochastic fractual search SFS is a point by point searching process used for a principal model decision. This schema utilizes the OBE computation and helps SFS to move away from Local Minima issue. SFS is susceptible to get trapped by this local minimum value where nearby a global minimum value is available, which is the desired goal state which the optimization algorithm should try to reach. Fractional calculus plays a vital role in enhancing the efficiency of different algorithms used in diverse engineering fields such as Image segmentation, Image or Pattern Classification, Curve Fitting, Stability analysis, Mathematical modelling etc. The Darwinian PSO (ISFS) uses the concept of natural selection [24] based on the fitness rate or the survival rate of the parameter. It's purely an evolutionary based concept in which each parameter is considered as a evolutionary based member and selection of parameters is grounded on the Darwinian concept of "survival of the fittest". This procedure is used artificially by creating agents. These agents interact with the environment and generate a local knowledge. This knowledge is utilized to develop a global function which describes the collective behaviors of all the agents[37]. The general algorithm for a PSO based optimization is provided below,

3.1. STOCHASTIC FRACTAL SEARCH ALGORITHM

SFS is population-based algorithm developed recently which imitates natural phenomenon of growth and diffusion process based on random fractals. The SFS mainly has two processes: diffusion process and update process, which can be depicted in Figure. 1.

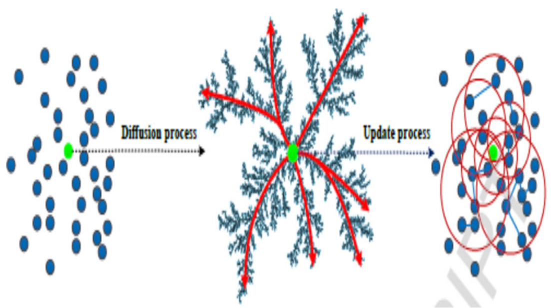

Figure.1. Main procedure of SFS algorithm.

The diffusion process is performed as exploitation strategy in SFS based on a series of Gaussian random walks listed as follows [26]:

$$GW_1 \ \text{Gaussian}(rand(0,1)\, P_{best} \ \ rand(0,1)\, P_i) \quad (1)$$

$$GW_2 \ \ Gaussian\,(\text{P}) \quad (2)$$

3.2 IMPROVED STOCHSTIC FRACTAL SEARCH ISFS

ISFS scheme is designed to make full use of the balance between exploitation and exploration to complement the advantages of SFS algorithm, OBL method and DE-based local search strategy. The procedure of the proposed ISFS is shown in Fig. 3 and the detailed description is presented as follows.

In the initialization process, the OBL method is utilized to achieve fitter starting individuals. To be specific, $2N_P$ individuals are generated first by the OBL method as given below, among which N_P best individuals are selected as the initial population.

$$x_{ij} \quad LB_j \quad rand \ (0,1) \ (UB_j \ -LB_j) \quad (3)$$

$$x_{(N_p \ i)j} \quad LB_j \quad UB_j - x_{ij} \quad (4)$$

Where $i = 1, 2, N_P$, j = 1, 2... D is the lower and upper bounds for dimension *j* respectively.

4. BRIEF OUTLINE ABOUT OF BLACK WIDOWS LIFESTYLE

The female black widow spider comes only at night and spins the web during night. Generally, it lives in the same site from adult. When the spiders want to mate, it marks spots on the web with the chemical to attract male spiders. The first male spider which enters the web renders female and result in web collapse. Then, the female consumes the male post mating and transfers eggs to egg sock. After it hatches, the off springs enters in sibling's cannibalism. They stay in web for some time and then even consume the mother. This cycle continues till the survival of the fittest [33, 34]. Finally, the best one in the globe, survives and enters the other cycle of mating as shown in Figure.2

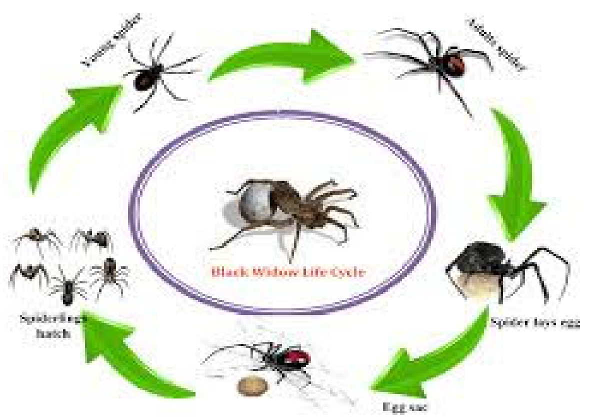

Figure.2 Life cycle of Black Widow spider

Female characters such as body condition, mating, position impact cannibalism for male spiders for being getting attacked. The spider is the only animal who engages in cannibalism of mal. Even, if the male was not consumed, they may die of themselves by injuries. A female can lay 4 to 10 egg sacs with about 250 eggs.

3.1. SIBLING CANNIBALISM

There are 3 cannibalisms. The first one is sexual, sibling, and mother. The egg got hatched in 8 days. They may leave the web or carried by wind. Cannibalism is mostly linked to demography. Population size depends on density. Still, eating of siblings is not understood. Sometimes cannibalism of offspring's may increase fitness of parents and survivors of the fittest. In some cases, the unfertilized spider eat the mother whereas the underweight offspring's are unable to eat the mother.

3.2. BLACK WIDOW OPTIMIZATION ALGORITHM

BWO algorithm was developed based on mating habit of black widow spider. The female spider first consumes the mating male and after that the eggs are hatched in egg sac. The baby spider again engages in sibling cannibalism. Hence the best, nr individuals were selected as parents for the next cycle. The pair of children are designated as

$$y1 = \alpha * X_{p1} + (1-\alpha) * X_{p2} \quad (5)$$

$$y1 = \alpha * X_{p2} + (1-\alpha) * X_{p1} \quad (6)$$

$$\alpha - U(0,1), \quad (7)$$

$y1$ and $y2$ are children. As the parent produces more children, y1 and y2 the population increases.

3.3. PROBLEM FORMULATION

The objective of MAPD [11] is to reduce the fuel costs of the powers systems by establishing the output powers of generating units from every region and the powers transferring among areas though satisfy a variety of operational constraints. In the contexts of various regions, an electricity system with NU generating units and M Area is deemed. Each area has Ni generating units. For an area with surplus powers, it is essential to finds a tie-line to transmit extra powers to a deficient area of power. Consider the costing of transmissions through each tie-line, the objectives functions of MAPD are provided by [10],

$$Min \cos t \sum_{i=1}^{M}\sum_{j=1}^{Ni} FC_{ij}(P_{ij}) + \sum_{i=1}^{M}\sum_{k=i+1}^{M} fc_{ik}T_{ik}(P_{ij}) \quad (8)$$

Where Pij is the powers flows of generating units j from areas i; FCij is the fuel cost function related with unit i from areaj, which can be expressed by a quadratic polynomial function as [11, 35], Tik and fcik are the tie-line power flow to area k from area i and its equivalent generation cost function,

$$FC_{ij}(P_{ij}) = a_{ij}P_{ij}^{\ 2} + b_{ij}P_{ij} + c_{ij} \quad (9)$$

Taking into considerations the valve-points effect of the unit, the fuel costing functions can be described as follows [12, 67],

$$FC_{ij}(P_{ij}) = a_{ij}P^2 + b_{ij}P_{ij} + c_{ij}\left|e_{ij}\sin(f_{ij}(P_{ij}^{\min} - P_{ij}))\right| \quad (10)$$

Where ,aij,, bij, ,cij are the factors of generating unit i in area j. eij and fij are constants of unit i from area j signifying the valve-point effects.

Furthermore, the objective function (2) is reduced subject to the subsequent limits:

(1) Power generation limits

The active powers outputs of the unit should be between their lower and upper limits [11].

$$P_{ij}^{\min} \le P_{ij} \le P_{ij}^{\max} \quad i = 1,2,....N_i; j = 1,2,..M \quad (11)$$

where Pij_{min} and Pij_{max} are the actual power operational limits for unit i from area j.

(2) Prohibited operating zones (POZ)

Consider the prohibits zone, the allowed operational areas for unit i from the area j are [11],

$$\begin{cases} P_{ij}^{\min} \le P_{ij} \le P_{ij,1}^{l} \\ P_{ij,z-1}^{u} \le P_{ij} \le P_{ij,z}^{l} \quad , z = 2,3,\ldots\ldots, NZ_{ij} \\ P_{ij,NZ_{ij}}^{u} \le P_{ij} \le P_{ij,1}^{\max} \end{cases} \quad (12)$$

Where, Pij,z-1 u and Pij,z-1 l are the lower and upper bounds of POZ of z. NZij is the number of POZ of unit i in area j. The fuel cost curve of considering POZ is described in Figure 3.

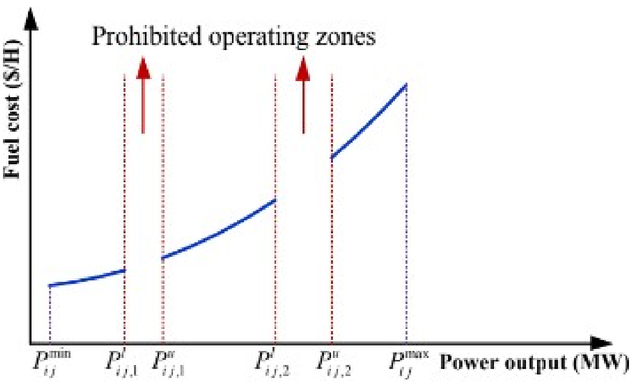

Figure 3. Fuel expense curve with two POZs

(3) Tie line power transfer limit

The tie-line real power flow to area i from area k (Tik) should be amongst the limits of tie line power transmission capability [12].

$$T_{ik}^{\min} \le T_{ik} \le T_{ik}^{\max} \quad i = 1,2,\ldots M, \quad k = 2,\ldots\ldots,M, i \ne k \quad (13)$$

Where Tik_{max} and Tik_{min} are the maximum and minimum capabilities of the tie-line for the power transmission to area i from area k.

(4) Thermal generation unit ramp rate limits

$$\max(p_{ij}^{\min 0}, P_{ij}^{0} - DR_{ij} \le P_{ij} \le \min(P_{ij}^{\max}, P_{ij}^{0} + UR_{ij}) \quad (14)$$

Where the DRi jand URij are the down and up ramp rate-limits of unit I from area j, and Pij0is the real power output of unit I from area j. [11]

(5) Real power balance

The real power balance constraint so the system for areas i without considerations of networks loss can be provided as [11]:

$$PG_i = PD_i + \sum_{k=1,k\ne i}^{N_i} T_{ik}, k = 1,2,\ldots\ldots, N_i \quad (15)$$

Where PGi is the overall engendered power in area i, PDi is the load requirement in area i.

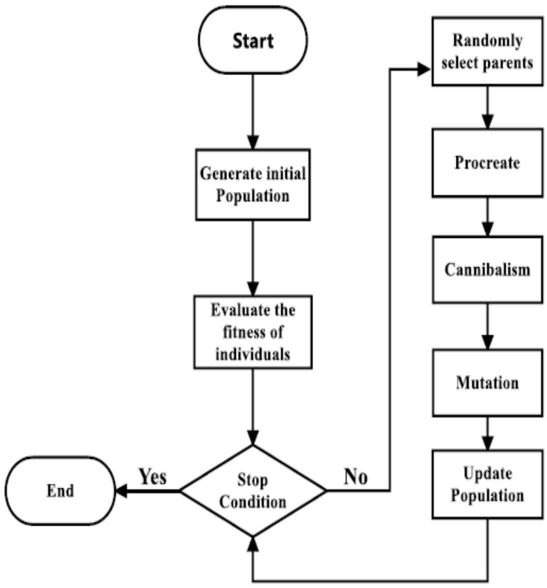

Figure.4. Black Widow Algorithm

The mother and baby spider are sorted to an array of fitness value. Then, the population was restored to cannibalism and the parents are chosen for mutation in random manner. Figure 4 shows the BWO algorithm where the survival of fittest is the outcome of this non elite algorithm. Figure.4 shows the pseudo code for BWO. There are several applications such as clustering, cloud computing, features selection, information retrieval, document clustering, IoT, text and hybrid clustering [26].

In this step, the population is consists of number of widows with size N, where each widow can be represented as an array of 1×Nvar representing the solution of the problem. This array can be defined

as widow = (x1, x2, ..., xNvar), where Nvar is the dimension of the optimization problem. Also Nvar can be defined as the number of threshold values needed to be obtained by the algorithm, while xi is the i–th candidate solution.

The fitness of a widow is obtained by evaluation of fitness function of f of each widow of the set (x1, x2, xNvar). Then fitness = f(widow) which can be represented by: fitness = f(x1, x2, ..., xNvar). In our proposed method we can replace f with the fitness function Otsu Eq.8 or Kapur Eq.14. The optimization process begins by randomly initializing a population of spiders in a matrix of size Npop×Nvar.

Then pairs of parents are randomly selected to perform the procreating step followed by the mating process, in which the male black widow is eaten by the female during or after that.

Step 2: Procreate

In the procreation step an array called alpha _ should be created as long as a widow array with random numbers containing. Then offspring is produced by using _ and the Eq.16 in which x1 and x2 are parents, y1 and y2 are offspring. The crossover result is evaluated and stored.

$$y1 = \alpha \times x1 + (1 - \alpha) \times x2 \text{ and } y2 = \alpha \times x2 + (1 - \alpha) \times x1 \quad (16)$$

3.4. Pseudo code for BWO Algorithm

Initialize: Maximum number of iterations, Rate of procreating, rate of Cannibalism, rate of mutation;
while Stop condition not met do
for i = 1 to nr do
Randomly select two solutions as parents from pop1.
Generate D children using Eq.16.
Destroy father.
Based on the cannibalism rate, destroy some of the children (newly achieved solutions).
Save the remaining solutions into pop2.
end for
Based on the mutation rate, calculate the number of mutation children nm.
for i = 1 to nr do
Select a solution from pop1.
Mutate randomly one chromosome of the solution and generate a new solution.
Save the new one into pop2.
end for
Update pop=pop2+pop3.
Returning the best solution.
Return the best solution from pop.
end while

4. RESULT & DISCUSSION

In this research work, the proposed calculation is done on 3 test frameworks. Test system 1 has 16 units. These 16 units are from four areas with each area having four generating units [23]. These details are recorded in Table 1.

4.1. First Test system

The summation of system demand was estimated at 1250 MW, with maximum capacity 300 MW. The best, mean, worst power demand and standard deviation SD for independent runs were listed in Table 2 comparing with HSLSO, CGBABC, SFS, ISFS and BWO. It was observed that the BWO had the best results than others and produced optimal results with least error. This shows the robustness of BWO in solving engineering problems. The accurate solutions of the entire algorithm are compared in Table 3. It could be concluded that BWO showed the lowest cost and more convergence characteristics as shown in Figure.5. BWO algorithm converged at optimal solutions with in 50 iterations in each run confirming the robustness of comparison.

Table 1: Test system 1 with16 Units

Units	a_{ij}	b_{ij}	c_{ij}	P_{ij}^{min}	P_{ij}^{max}
$P_{1,1}$	0	4	0.01	50	150
$P_{1,2}$	0	2	0.03	25	100
$P_{1,3}$	0	3	0.05	25	100
$P_{1,4}$	0	1	0.04	25	100
$P_{2,1}$	0	4	0.05	50	150
$P_{2,2}$	0	2	0.04	2	100
$P_{2,3}$	0	3	0.08	25	100
$P_{2,4}$	0	1	0.06	25	100
$P_{3,1}$	0	4	0.1	50	150
$P_{3,2}$	0	2	0.12	25	100
$P_{3,3}$	0	3	0.1	25	100
$P_{3,4}$	0	1	0.13	25	100
$P_{4,1}$	0	4	0.01	50	150
$P_{4,2}$	0	2	0.03	25	100
$P_{4,3}$	0	3	0.05	25	100
$P_{4,4}$	0	1	0.04	25	100

Table 2.Statistical analysis of algorithms for System 1

Optimization Algorithm	HSLSO	CGBABC,	SFS	ISFS	BWO
Best	7009.7161	7007.841	7008.4135	7007.5775	7007.4991
Mean	7015.4387	7058.6157	7014.1113	7007.5972	7007.5121
Worst	7040.5224	7152.7203	7037.9089	7007.6548	7007.5384
SD	6.7853	48.6011	6.5412	0.0217	0.0124

Table 3. Simulation Results for 16-Unit system 4 Area Pd=1250 (32/16/28/24) T=100

Methods	HSLSO	CGBABC	SFS	ISFS	BWO
$P_{1,1}$	150	150	150	150	150
$P_{1,2}$	100	100	100	100	100
$P_{1,3}$	63.7634	63.7241	65.5211	63.6743	63.70
$P_{1,4}$	100	100	100	100	100
$P_{2,1}$	50	53.6632	54.0502	53.6948	53.66
$P_{2,2}$	93.2896	92.0843	91.0586	92.3936	92.4133
$P_{2,3}$	39.3285	39.7918	38.7951	39.7369	39.7371
$P_{2,4}$	70.0960	69.7218	68.7363	69.5910	69.611
$P_{3,1}$	50	50	50.0094	50	50
$P_{3,2}$	35.8741	34.8650	35.0614	34.7407	34.688
$P_{3,3}$	35.5041	36.8380	36.4894	36.6518	36.702
$P_{3,4}$	35.2017	36.0322	36.3900	36.0063	36.10
$P_{4,1}$	150	150	149.9490	150	150
$P_{4,2}$	100	100	100	100	100
$P_{4,3}$	76.9426	73.2796	73.9393	73.5107	73.49
$P_{4,4}$	100	100	100	100	100
T_{12}	-99.5804	-100	-99.9528	-100	-100
T_{13}	98.2552	37.0037	78.8538	90.4111	90.3902
T_{14}	15.0886	76.7204	36.6201	23.2631	23.2429
T_{23}	-4.7962	55.2611	13.3832	2.1923	2.20
T_{24}	-42.0702	-100	-60.6957	-46.7760	-46.7458
T_{43}	-99.9611	-100	-99.8126	-99.9978	-99.9881
P_{Demand}	1250.00	1250.00	1250.00	1250.00	1250.00
Cost	7009.7161	7007.5841	7008.4135	7007.5775	7007.4991

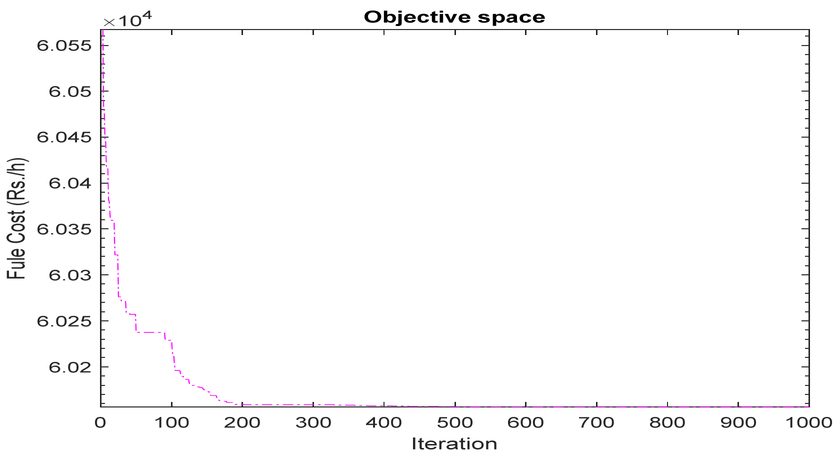

Figure 7. Convergence graph for the data provided in Table 1 using the proposed method.

Table 4. Two tailed paired test for algorithms on test system 1

Algorithm	Mean (SD)	SD	Error	Confidence Interval	T value	Significance
BWO vs HSLSO	-7.842	7.23	1.53	95%	-6.23	0.00
BWO vs CGBABC	-8.21	12.54	2.35	95%	-7.56	0.00
BWO vs SFS	-23.25	32.1	8.26	95%	-5.34	0.00
BWO vs ISFS	-9.45	6.82	1.25	95%	-6.15	0.00

A two tailed paired test was done for all algorithms at 95% confidence level, the results are listed in Table 4, here from the table it was observed that significance of 0 represents that BWO is statistically different from others and can be a best algorithm to predict the performance of cost and power in this paper.

4.2. Second Test system

The second test system has 2 areas with 40 generating units. The 40-unit characteristics data for system 2 is shown in Table.5 [23]. The cost and power data are available in Tables 7 (a), (b). The total system load demand is 10500 MW with active 7500 MW for area 1 and 3000 MW for area 2, loads respectively. The simulation results are compared with other algorithms. It is clear that BWO is superior to SFS, HSLSO, ISFS and CGBABC algorithms. The fuel cost is much low for BWO and the SD values were least. The solutions of BWO is feasible with no violations in tie-line and generating unit limits, ramp-rate limits and POZs, are fully satisfied. The statistical results in table.6 of the two-tailed t-test at 95% confidence level showed BWO is significantly stable and robust.

Table 5: Characteristics data for test system 2 with 40 Units

Units	a_{ij}	b_{ij}	c_{ij}	e_{ij}	f_{ij}	P_{ij}^{min}	P_{ij}^{max}	P_{ij}^{0}	UR_{ij}	DR_{ij}	POZs
$P_{1,1}$	0.0069	6.73	94.705	100	0.084	36	114	100	114	114	
$P_{1,2}$	0.0069	6.73	94.705	100	0.084	36	114	100	114	114	
$P_{1,3}$	0.02028	7.07	309.54	100	0.084	60	120	90	120	120	
$P_{1,4}$	0.0042	8.18	369.03	150	0.063	80	190	150	100	150	
$P_{1,5}$	0.0114	0.3	148.89	120	0.077	47	97	80	97	97	
$P_{1,6}$	0.01142	8.05	222.33	100	0.084	6	140	120	80	125	
$P_{1,7}$	0.0037	8.03	287.71	200	0.042	110	300	280	165	200	
$P_{1,8}$	0.0042	6.99	391.98	200	0.042	135	300	200	165	200	
$P_{1,9}$	0.00573	6.6	455.76	200	0.042	135	300	230	165	200	
$P_{1,10}$	0.00605	12.9	722.82	200	0.042	130	300	240	155	190	(130,150) (200,230), (270,299)
$P_{1,11}$	0.00515	12	635.2	200	0.042	94	375	210	150	185	(100,140)(230,280)(300,350)
$P_{1,12}$	0.00569	12.8	654.69	200	0.042	94	375	210	10	185	(100,140)(230,280)(300,350)
$P_{1,13}$	0.00421	12.5	913.4	300	0.035	125	500	230	206	235	(50,200) (250,300) (400,450)
$P_{1,14}$	0.00752	8.84	1760.4	300	0.035	125	500	355	260	290	(200,250)(300,350)(450,490)

P1,15	0.00708	9.15	1728.3	300	0.035	125	500	350	186	215	
P1,16	0.00708	9.15	1728.3	300	0.035	125	500	350	186	215	
P1,17	0.00313	7.97	647.85	300	0.035	220	500	460	240	270	
P1,18	0.00313	7.95	649.69	300	0.035	220	500	470	240	268	
P1,19	0.00313	7.97	647.83	300	0.035	242	550	500	290	315	
P1,20	0.00313	7.97	647.81	300	0.035	242	550	500	290	315	
P2,1	0.00298	6.63	785.96	300	0.035	254	550	510	335	360	
P2,2	0.00298	6.63	785.6	300	0.035	254	550	520	335	360	
P2,3	0.00284	6.66	794.53	300	0.035	254	550	520	33	362	
P2,4	0.00284	6.66	794.53	300	0.035	254	550	450	350	378	
P2,5	0.00277	7.1	801.32	300	0.035	254	550	400	350	380	
P2,6	0.00277	7.1	801.32	300	0.035	254	550	520	350	380	
P2,7	0.52124	3.33	1055.1	120	0.077	10	150	20	95	145	
P2,8	0.5212	3.33	1055.1	120	0.077	10	150	20	95	145	
P2,9	0.5212	3.33	1055.1	120	0.077	10	150	25	98	145	
P2,10	0.0114	5.35	148.89	150	0.077	47	97	90	97	97	
P2,11	0.0016	6.43	222.92	150	0.063	60	190	170	90	145	
P2,12	0.0016	6.43	222.92	150	0.063	60	190	150	90	145	
P2,13	0.0016	6.43	222.92	200	0.063	60	190	190	90	145	
P2,14	0.0001	8.95	107.87	200	0.042	90	200	190	105	150	
P2,15	0.0001	8.62	116.58	200	0.042	90	200	150	105	150	
P2,16	0.0001	8.62	116.58	80	0.042	90	200	180	105	150	
P2,17	0.0161	5.88	307.45	80	0.098	25	110	60	110	110	
P2,18	0.0161	5.88	307.45	80	0.098	25	110	40	110	110	
P2,19	0.0161	5.88	307.45	80	0.098	25	110	50	110	110	
P2,20	0.00313	7.97	647.83	300	0.035	242	550	512	290	315	

Table 6 .Statistical analysis of algorithms for System 2

Optimization Algorithm	HSLSO	CGBABC	SFS	ISFS	BWO
Best	125879.934	125240.439	124750.579	124683.097	124680.65
Mean	126216.645	125730.61	124975.13	124818.103	124653.25
Worst	126567.281	126168.275	125209.46	125062.67	124736.31
SD	162.631	229.095	12.5477	86.117	75.62

Table 7 (a) Simulation Results for 40-Unit system 2 Area Pd=10500 (60/40) T=1500

Methods	HSLSO	CGBABC	SFS	ISFS	BWO
$P_{1,1}$	113.8349	114	113.8755	113.9058	113.8808
$P_{1,2}$	1119357	114	113.9917	114	114
$P_{1,3}$	118.4896	120	119.9649	119.9864	119.9964
$P_{1,4}$	183.7781	190	179.9618	179.9941	179.9939
$P_{1,5}$	97	97	96.9975	97	97
$P_{1,6}$	139.9985	140	139.9921	140	140
$P_{1,7}$	297.7845	300	299.9718	300	300
$P_{1,8}$	294.0095	300	292.0177	291.3401	293.3499
$P_{1,9}$	295.4437	300	286.2145	287.0178	285.0168
$P_{1,10}$	200	270	199.9963	200	200
$P_{1,11}$	151.6280	168.7998	168.8617	230	230
$P_{1,12}$	230	168.7998	229.9937	168.8385	168.8379
$P_{1,13}$	394.2025	304.5196	394.2861	394.2548	394.2944
$P_{1,14}$	490	394.2794	394.3472	394.2946	394.2944
$P_{1,15}$	472.1173	484.0392	484.0810	484.0588	484.0188
$P_{1,16}$	394.0728	484.0392	484.0282	483.9991	483.9989
$P_{1,17}$	494.7530	489.2794	489.4175	489.3491	489.3489
$P_{1,18}$	492.1624	499.9643	489.4217	489.3036	489.3036
$P_{1,19}$	510.8584	550	511.3790	511.3242	511.3239
$P_{1,20}$	517.9578	511.2794	511.2666	511.3414	511.3414
$P_{2,1}$	524.6083	533.5196	433.5220	433.42	433.42
$P_{2,2}$	437.6060	523.2794	433.4372	523.0749	523.1749
$P_{2,3}$	442.0369	523.2794	523.2303	523.2439	523.1439
$P_{2,4}$	423.4167	523.2794	433.5201	523.2985	523.2985
$P_{2,5}$	431.5304	523.2794	433.4048	433.3512	433.4212
$P_{2,6}$	524.2870	433.5196	523.3005	433.4643	433.3943
$P_{2,7}$	10.8217	10	10.0091	10.0034	10.0034
$P_{2,8}$	10	10	10.0201	10	10
$P_{2,9}$	12.1197	10	10.0004	10	10
$P_{2,10}$	89.3499	87.7999	87.7942	87.8100	87.7900
$P_{2,11}$	166.0768	159.7331	189.4315	159.6862	159.7059
$P_{2,12}$	163.0429	190	159.7266	189.3811	189.3791
$P_{2,13}$	157.8148	190	159.7200	159.7251	159.7249
$P_{2,14}$	162.3617	90	164.8297	164.6679	164.7679
$P_{2,15}$	162.1677	90	164.7029	164.8266	164.8362
$P_{2,16}$	161.9376	164.7998	164.7322	164.6281	164.7291
$P_{2,17}$	88.0872	110	88.9974	89.1646	89.0646
$P_{2,18}$	96.9268	89.1141	88.8668	89.1364	89.0371
$P_{2,19}$	93.6130	96.3964	89.0476	89.1093	89.1090
$P_{2,20}$	342.1681	242	331.6393	242	242
T_{12}	-1499.9732	-1500	1499.9337	-1499.9915	-1500
Cost	125879.9346	125240.4399	124750.5796	124683.0977	124680.65

Table. 7 (b) 2 area-40 unit Dispatch

Power Outputs in Area 1 (MW)				**Power Outputs in Area 2 (MW)**			
$P_{1,1}$	113.8808	$P_{1,11}$	230	$P_{2,1}$	433.42	$P_{2,11}$	159.7059
$P_{1,2}$	114	$P_{1,12}$	168.8379	$P_{2,2}$	523.1749	$P_{2,12}$	189.3791
$P_{1,3}$	119.9964	$P_{1,13}$	394.2944	$P_{2,3}$	523.1439	$P_{2,13}$	159.7249
$P_{1,4}$	179.9939	$P_{1,14}$	394.2944	$P_{2,4}$	523.2985	$P_{2,14}$	164.7679
$P_{1,5}$	97	$P_{1,15}$	484.0188	$P_{2,5}$	433.4212	$P_{2,15}$	164.8362
$P_{1,6}$	140	$P_{1,16}$	483.9989	$P_{2,6}$	433.3943	$P_{2,16}$	164.7291
$P_{1,7}$	300	$P_{1,17}$	489.3489	$P_{2,7}$	10.0034	$P_{2,17}$	89.0646
$P_{1,8}$	293.3499	$P_{1,18}$	489.3036	$P_{2,8}$	10	$P_{2,18}$	89.0371
$P_{1,9}$	285.0168	$P_{1,19}$	511.3239	$P_{2,9}$	10	$P_{2,19}$	89.1090
$P_{1,10}$	200	$P_{1,20}$	511.3414	$P_{2,10}$	87.7900	$P_{2,20}$	242
Tieline flow (MW) = -1500							
Total cost ($) = 124680.65							

Table 7 (c) 2 area-40 unit Comparison

Method	**HSLSO**	**CGBABC**	**SFS**	**ISFS**	**BWO**
Total cost	125879.9346	125240.4399	124750.5796	124683.0977	124680.65

Table 7.1, 7.2, 7.3 shows the Simulation Results for 40-Unit system 2 Area Pd=10500 (60/40) T=1500 and comparison of algorithms prediction for cost optimization. From all the algorithms, BWO showed the best simulation with least cost optimization.

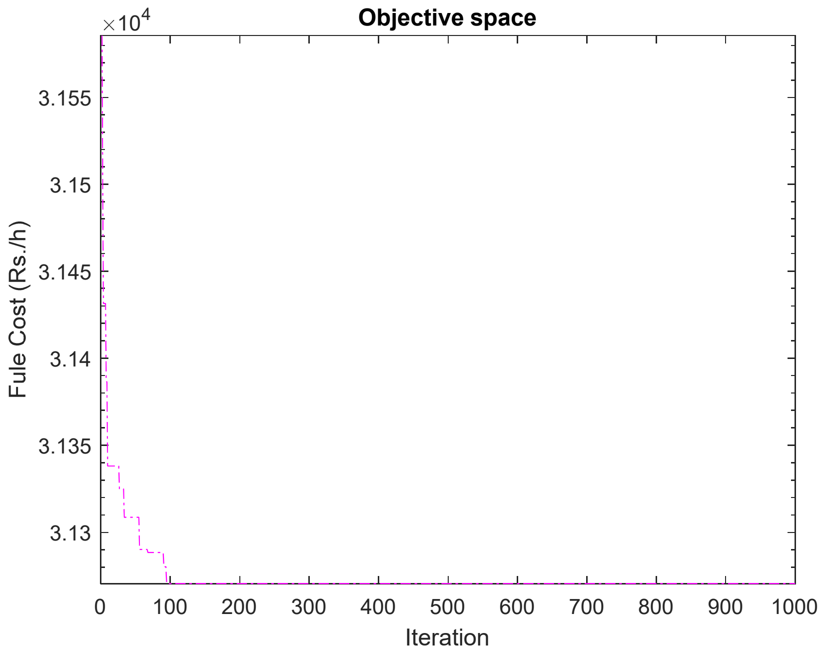

Figure.6. Convergence graph for the data provided in Table 2 using the proposed method.

Table 8. Two tailed paired test for algorithms on test system 2

Algorithm	Mean	SD	Error	Confidence Interval	T value	Significance
BWO vs HSLSO	-1397.543	199.85	36.48	95%	-38.38	0
BWO vs CGBABC	-260.3	252.16	3.53	95%	-19.56	0
BWO vs SFS	-337.7	171.63	18.26	95%	-9.34	0
BWO vs ISFS	-262.9	156.23	5.35	95%	-5.15	0

A two tailed paired test was done for all algorithms at 95% confidence level, the results are listed in Table 8, here from the table it was observed BWO is the statistically best algorithm for optimization of cost and power converged at 100 iterations. The values of SD are least and p test 0 indicates the statistically different algorithm.

4.3. Third Test System

The third test system consists of 120 units from two areas of each having 70 and 50 generating units. The input data for this system which is a mixture of coal, oil, gas and nuclear fuels are shown in Table 9.

Table 9 (a). Simulation Results for 120-Unit system 2 Area Pd=28000 (65/35) T=2000

Methods	HSLSO	CGBABC	SFS	ISFS	BWO
$P_{1,1}$	79.9982	80.0000	79.5612	79.9998	79.9999
$P_{1,2}$	120.0000	120.0000	119.8453	120.0000	120.0000
$P_{1,3}$	189.9953	190.0000	189.9857	190.0000	190.0000
$P_{1,4}$	41.7163	42.0000	40.2266	42.0000	42.0000
$P_{1,5}$	42.0000	41.0089	39.7159	40.9657	40.9956
$P_{1,6}$	139.9828	140.0000	139.8996	140.0000	140.0000
$P_{1,7}$	299.9161	300.0000	299.9479	300.0000	300.0000
$P_{1,8}$	300.0000	300.0000	299.7236	300.0000	300.0000
$P_{1,9}$	300.0000	300.0000	299.8765	299.9999	299.9999
$P_{1,10}$	136.8128	132.3604	153.2446	131.7248	131.6951
$P_{1,11}$	145.3807	148.0052	156.4978	147.6409	147.5912
$P_{1,12}$	154.8629	150.6989	132.3224	150.2374	150.277
$P_{1,13}$	243.0890	238.7620	242.8100	238.4154	238.3958
$P_{1,14}$	376.1310	377.0213	354.4352	376.8136	376.7939
$P_{1,15}$	378.6783	378.1405	354.4942	377.4680	377.5080
$P_{1,16}$	379.6638	378.0741	361.7414	377.6985	377.7188
$P_{1,17}$	383.8889	378.0777	386.0747	377.4253	377.4450
$P_{1,18}$	499.9666	500.0000	499.8777	500.0000	500.0000
$P_{1,19}$	499.9120	500.0000	499.6008	500.0000	500.0000
$P_{1,20}$	549.8269	550.0000	549.9474	549.9999	549.9999
$P_{1,21}$	550.0000	550.0000	549.8431	550.0000	550.0000
$P_{1,22}$	550.0000	550.0000	549.8969	549.9995	549.9999
$P_{1,23}$	549.8782	550.0000	549.9997	550.0000	550.0000
$P_{1,24}$	549.9859	550.0000	549.9839	550.0000	550.0000

$P_{1,25}$	549.9880	550.0000	549.9884	550.0000	550.0000
$P_{1,26}$	549.9459	550.0000	549.8298	549.9999	549.9999
$P_{1,27}$	549.9206	550.0000	549.8574	550.0000	550.0000
$P_{1,28}$	10.8546	10.7288	11.2914	10.7145	10.7241
$P_{1,29}$	10.9989	10.7267	10.3940	10.7337	10.7241
$P_{1,30}$	10.6543	10.7183	10.5104	10.7327	10.7227
$P_{1,31}$	20.0681	20.0000	20.0181	20.0000	20.0000
$P_{1,32}$	20.0558	20.0000	20.0000	20.0000	20.0000
$P_{1,33}$	20.0600	20.0000	20.0572	20.0000	20.0000
$P_{1,34}$	20.0465	20.0000	20.0291	20.0000	20.0000
$P_{1,35}$	18.0163	18.0000	18.0094	18.0000	18.0000
$P_{1,36}$	18.0911	18.0000	18.0473	18.0000	18.0000
$P_{1,37}$	20.0290	20.0000	20.0610	20.0001	20.0000
$P_{1,38}$	25.0412	25.0000	25.0160	25.0000	25.0000
$P_{1,39}$	25.0406	25.0000	25.0249	25.0001	25.0000
$P_{1,40}$	25.0369	25.0000	25.0179	25.0001	25.0000
$P_{1,41}$	79.7118	80.0000	79.5572	79.9999	79.9999
$P_{1,42}$	119.7478	120.0000	119.8252	120.0000	120.0000
$P_{1,43}$	189.8078	190.0000	189.8969	190.0000	190.0000
$P_{1,44}$	41.9733	42.0000	41.8685	42.0000	42.0000
$P_{1,45}$	40.4318	40.9769	40.6311	41.1071	41.1173
$P_{1,46}$	139.9328	140.0000	139.6749	140.0000	140.0000
$P_{1,47}$	299.8971	300.0000	299.9773	300.0000	300.0000
$P_{1,48}$	299.9911	300.0000	299.9095	300.0000	300.0000
$P_{1,49}$	299.9900	300.0000	299.9639	299.9999	299.9999
$P_{1,50}$	139.8929	132.5278	137.8236	132.1170	132.0969
$P_{1,51}$	157.3501	148.0361	186.0553	147.7207	147.7211
$P_{1,52}$	152.9510	150.4748	158.7896	150.4959	150.5161
$P_{1,53}$	242.3149	238.6551	209.5653	237.9327	237.9327
$P_{1,54}$	374.4340	376.9667	355.9982	376.3264	376.2968
$P_{1,55}$	379.8989	378.1754	318.6330	377.7294	377.7591
$P_{1,56}$	387.2620	378.1414	365.7623	378.1064	378.0906
$P_{1,57}$	383.6060	378.1810	363.0047	377.5702	377.576
$P_{1,58}$	499.9915	500.0000	499.8835	500.0000	500.0000
$P_{1,59}$	499.9633	500.0000	499.9224	499.9999	499.9999
$P_{1,60}$	549.9419	550.0000	549.9964	549.9999	549.9999
$P_{1,61}$	549.9582	550.0000	549.9240	550.0000	550.0000
$P_{1,62}$	549.9929	550.0000	549.9161	550.0000	550.0000
$P_{1,63}$	549.9581	550.0000	549.9367	549.9999	549.9999
$P_{1,64}$	549.9471	550.0000	549.9134	550.0000	550.0000
$P_{1,65}$	549.9267	550.0000	549.9822	550.0000	550.0000
$P_{1,66}$	549.9976	550.0000	549.9544	549.9999	549.9999
$P_{1,67}$	549.9060	550.0000	549.9740	550.0000	550.0000
$P_{1,68}$	10.3343	10.7142	10.2331	10.7166	10.7168

$P_{1,69}$	11.1451	10.7047	11.2266	10.6969	10.7167
$P_{1,70}$	10.3729	10.7251	10.0403	10.7224	10.7126
$P_{2,1}$	20.0002	20.0000	20.0154	20.0000	20.0000
$P_{2,2}$	20.0267	20.0000	20.0034	20.0000	20.0000
$P_{2,3}$	20.0336	20.0000	20.0584	20.0000	20.0000
$P_{2,4}$	20.0814	20.0000	20.0656	20.0000	20.0000
$P_{2,5}$	18.0103	18.0000	18.0035	18.0000	18.0000
$P_{2,6}$	18.0448	18.0000	18.0566	18.0001	18.0000
$P_{2,7}$	20.0184	20.0000	20.0027	20.0001	20.0000
$P_{2,8}$	25.0113	25.0000	25.0000	25.0000	25.0000
$P_{2,9}$	25.0173	25.0000	25.0722	25.0000	25.0000
$P_{2,10}$	25.0291	25.0000	25.0990	25.0000	25.0000
$P_{2,11}$	79.9540	80.0000	79.0052	79.9999	79.9999
$P_{2,12}$	119.8767	120.0000	120.0000	119.9999	119.9999
$P_{2,13}$	189.9395	190.0000	190.0000	189.9999	189.9999
$P_{2,14}$	40.9528	42.0000	39.0995	41.9988	41.9986
$P_{2,15}$	41.6218	40.9124	40.5015	40.9347	40.9951
$P_{2,16}$	139.8551	140.0000	140.0000	140.0000	140.0000
$P_{2,17}$	299.8559	300.0000	299.9438	300.0000	300.0000
$P_{2,18}$	299.9295	300.0000	300.0000	300.0000	300.0000
$P_{2,19}$	299.8548	300.0000	299.8648	299.9999	299.9999
$P_{2,20}$	135.0092	130.9722	196.1662	132.1851	132.1249
$P_{2,21}$	134.3625	146.3208	197.2869	147.0628	147.0632
$P_{2,22}$	136.2160	149.0551	158.8568	149.9532	149.9830
$P_{2,23}$	230.5824	236.7338	276.1682	237.8210	237.7912
$P_{2,24}$	373.5147	375.8565	343.5451	376.3718	376.4021
$P_{2,25}$	373.5080	376.8405	390.2322	377.6285	377.5985
$P_{2,26}$	369.8694	376.8168	371.7696	377.5627	377.5831
$P_{2,27}$	365.9713	376.8094	374.1437	377.6154	377.5949
$P_{2,28}$	499.9333	500.0000	499.9799	499.9997	499.9999
$P_{2,29}$	499.8151	500.0000	499.8863	500.0000	500.0000
$P_{2,30}$	549.9450	550.0000	549.9146	550.0000	550.0000
$P_{2,31}$	549.7542	550.0000	550.0000	549.9999	549.9999
$P_{2,32}$	549.8903	550.0000	550.0000	550.0000	550.0000
$P_{2,33}$	549.9253	550.0000	549.5289	549.9999	549.9999
$P_{2,34}$	549.9696	550.0000	550.0000	549.9999	549.9999
$P_{2,35}$	549.9869	550.0000	550.0000	550.0000	550.0000
$P_{2,36}$	549.9801	550.0000	549.7038	549.9999	549.9999
$P_{2,37}$	549.8911	550.0000	549.8260	550.000	550.000
$P_{2,38}$	10.4195	10.6955	10.3500	10.6831	10.6829
$P_{2,39}$	10.5987	10.6939	10.3579	10.6947	10.6845
$P_{2,40}$	10.4124	10.6908	10.7291	10.6778	10.6881
$P_{2,41}$	20.0168	20.0000	20.0171	20.0000	20.0000

$P_{2,42}$	20.0198	20.0000	20.0082	20.0000	20.0000
$P_{2,43}$	20.0118	20.0000	20.1050	20.0000	20.0000
$P_{2,44}$	20.0433	20.0000	20.0547	20.0000	20.0000
$P_{2,45}$	18.0000	18.0000	18.0005	18.0000	18.0000
$P_{2,46}$	18.0332	18.0000	18.0196	18.0000	18.0000
$P_{2,47}$	20.0109	20.0000	20.0025	20.0001	20.0000
$P_{2,48}$	25.0184	25.0000	25.0038	25.0000	25.0000
$P_{2,49}$	25.0151	25.0000	25.0030	25.0000	25.0000
$P_{2,50}$	25.0000	25.0000	25.0046	25.0000	25.0000
$T_{1,2}$	316.1625	263.6022	130.5443	256.8108	256.7911
P_{Demand}	28000.0000	28000.0000	28000.0000	28000.0000	28000.0000
Cost	377987.551	377958.370	378101.229	377958.330	377952.4721

Table 9 (b): 2 area-120 unit Dispatch

Power Outputs in Area 1 And Area 2 (MW)							
$P_{1,1}$	79.9999	$P_{1,31}$	20.0000	$P_{1,61}$	549.9999	$P_{2,21}$	147.0632
$P_{1,2}$	120.0000	$P_{1,32}$	20.0000	$P_{1,62}$	550.0000	$P_{2,22}$	149.9830
$P_{1,3}$	190.0000	$P_{1,33}$	20.0000	$P_{1,63}$	550.0000	$P_{2,23}$	237.7912
$P_{1,4}$	42.0000	$P_{1,34}$	20.0000	$P_{1,64}$	549.9999	$P_{2,24}$	376.4021
$P_{1,5}$	40.9956	$P_{1,35}$	18.0000	$P_{1,65}$	550.0000	$P_{2,25}$	377.5985
$P_{1,6}$	140.0000	$P_{1,36}$	18.0000	$P_{1,66}$	550.0000	$P_{2,26}$	377.5831
$P_{1,7}$	300.0000	$P_{1,37}$	20.0000	$P_{1,67}$	549.9999	$P_{2,27}$	377.5949
$P_{1,8}$	300.0000	$P_{1,38}$	25.0000	$P_{1,68}$	550.0000	$P_{2,28}$	499.9999
$P_{1,9}$	299.9999	$P_{1,39}$	25.0000	$P_{1,69}$	10.7168	$P_{2,29}$	500.0000
$P_{1,10}$	131.6951	$P_{1,40}$	25.0000	$P_{1,70}$	10.7167	$P_{2,30}$	550.0000
$P_{1,11}$	147.5912	$P_{1,41}$	79.9999	$P_{2,1}$	10.7126	$P_{2,31}$	549.9999
$P_{1,12}$	150.277	$P_{1,42}$	120.0000	$P_{2,2}$	20.0000	$P_{2,32}$	550.0000
$P_{1,13}$	238.3958	$P_{1,43}$	190.0000	$P_{2,3}$	20.0000	$P_{2,33}$	549.9999
$P_{1,14}$	376.7939	$P_{1,44}$	42.0000	$P_{2,4}$	20.0000	$P_{2,34}$	549.9999
$P_{1,15}$	377.5080	$P_{1,45}$	41.1173	$P_{2,5}$	20.0000	$P_{2,35}$	550.0000
$P_{1,16}$	377.7188	$P_{1,46}$	140.0000	$P_{2,6}$	18.0000	$P_{2,36}$	549.9999
$P_{1,17}$	377.4450	$P_{1,47}$	300.0000	$P_{2,7}$	18.0000	$P_{2,37}$	550.000
$P_{1,18}$	500.0000	$P_{1,48}$	300.0000	$P_{2,8}$	20.0000	$P_{2,38}$	10.6829
$P_{1,19}$	500.0000	$P_{1,49}$	299.9999	$P_{2,9}$	25.0000	$P_{2,39}$	10.6845
$P_{1,20}$	549.9999	$P_{1,50}$	132.0969	$P_{2,10}$	25.0000	$P_{2,40}$	10.6881
$P_{1,21}$	550.0000	$P_{1,51}$	147.7211	$P_{2,11}$	25.0000	$P_{2,41}$	20.0000
$P_{1,22}$	549.9999	$P_{1,52}$	150.5161	$P_{2,12}$	79.9999	$P_{2,42}$	20.0000
$P_{1,23}$	550.0000	$P_{1,53}$	237.9327	$P_{2,13}$	119.9999	$P_{2,43}$	20.0000
$P_{1,24}$	550.0000	$P_{1,54}$	376.2968	$P_{2,14}$	189.9999	$P_{2,44}$	20.0000
$P_{1,25}$	550.0000	$P_{1,55}$	377.7591	$P_{2,15}$	41.9986	$P_{2,45}$	18.0000
$P_{1,26}$	549.9999	$P_{1,56}$	378.0906	$P_{2,16}$	40.9951	$P_{2,46}$	18.0000
$P_{1,27}$	550.0000	$P_{1,57}$	377.576	$P_{2,17}$	140.0000	$P_{2,47}$	20.0000
$P_{1,28}$	10.7241	$P_{1,58}$	500.0000	$P_{2,18}$	300.0000	$P_{2,48}$	25.0000
$P_{1,29}$	10.7241	$P_{1,59}$	499.9999	$P_{2,19}$	300.0000	$P_{2,49}$	25.0000
$P_{1,30}$	10.7227	$P_{1,60}$	549.9999	$P_{2,20}$	299.9999	$P_{2,50}$	25.0000
Tie line flows (MW) = 256.7911							
Total cost ($) = 377952.4721							

Table 9 (c) 2 area-120 unit Comparison

Method	HSLSO	CGBABC	SFS	ISFS	BWO
Total cost	377987.551	377958.370	378101.229	377958.330	377952.4721

Table 10 .Statistical analysis of algorithms for System 3

Optimization Algorithm	HSLSO	CGBABC	SFS	ISFS	BWO
Best	337787.55	377988.52	377958.33	378101.22	377952.4721
Mean	378106.919	377536.02	378043.83	378227.18	377958.36
Worst	378295.1495	378295.14	378967.47	378587.75	377958.43
SD	85.006	88.003	210.18	131.80	0.0125

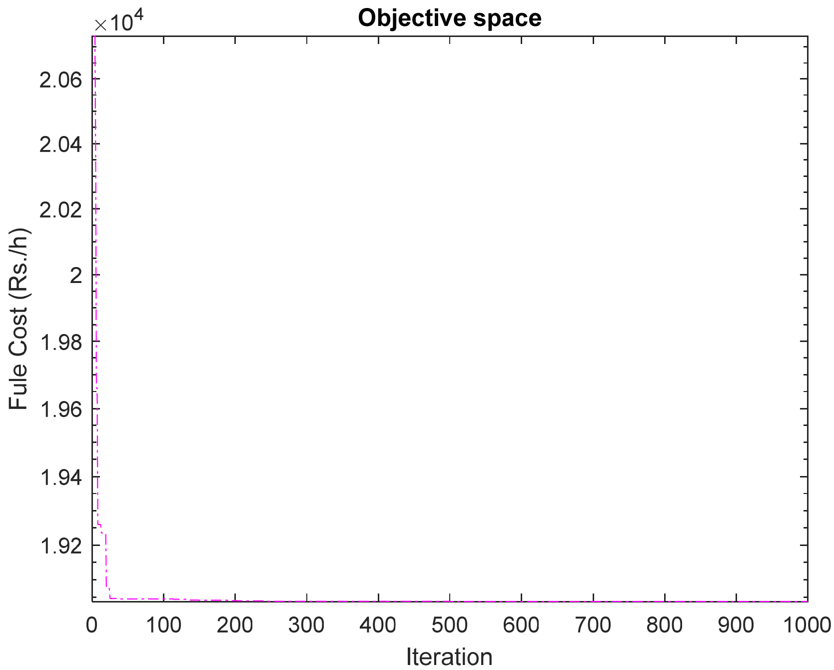

Figure.7 Convergence graph for the data provided in Table 3 using the proposed method.

Table 11. Two tailed paired test for algorithms on test system 3

Algorithm	Mean	SD	Error	Confidence Interval	T value	Significance
BWO vs HSLSO	-148.56	86.41	18.74	95%	-9.41	0
BWO vs CGBABC	-152.55	76.41	21.786	95%	-7.43	0.000
BWO vs SFS	-96.47	202.68	56.093	95%	-1.38	0.035
BWO vs ISFS	-275.82	163.03	12.106	95%	-12.15	0.012

6. CONCLUSION & FUTURE SCOPE

Optimization of load dispatch is a trivial issue. Economic load dispatch problems not only depend on the demand but also on the fuel cost, Transmission and distribution cost. Load dispatch varies with different regions using different power generation schemes such as Thermal, Hydro-electric, and Nuclear systems. Different regions have different power utilization demands and also it varies dynamically with time. Hence it necessitates a thorough research in the optimization of electrical load dispatch. Load dispatch problems are a concern among the power generation corporate due to the dynamic fluctuation of power and its associated generation cost.

In this research work a BWO based Single Objective Multi Area Economic load dispatch is designed and tested. It is evident from the results that our proposed methodology helps in reducing the overall cost for a multi-area generating units as discussed above. It is found from the experimental results shown as graphs in the results and discussion section, the speed of convergence depends on the fractional order σ. It is evident from the graphs that the proposed algorithm outpaces the traditional algorithms and ISFS¸ previously presented in the literatures. Though, each optimization procedure might have to some extent different optimal σ values. Therefore, as future work, we propose to extend the BWO with adaptability-based functions to tune the fractional order σ. In this case Fuzzy logic can be utilized to further improve the efficiency and adaptability of the optimization algorithms.

References

[1] C. K. Faseela, and H. Vennila, "Economic and emission dispatch using Whale Optimization Algorithm (WOA)," International Journal of Electrical and Computer Engineering, vol. 8, no.3, pp.1297, 2018.

[2] F. Mohamed, M. Abdel-Nasser, K. Mahmoud, and S. Kamel, "Economic dispatch using stochastic whale optimization algorithm," in 2018 International Conference on Innovative Trends in Computer Engineering, pp. 19–24, 2018.

[3] J. G. Vlachogiannis and K. Y. Lee, "Economic Load Dispatch—A Comparative Study on Heuristic Optimization Techniques With an Improved Coordinated Aggregation-Based PSO," IEEE Transaction on Power System, vol. 24, no. 2, pp. 991–1001, 2009.

[4] R. Al-Nahhal, A. F. Naiem, and Y. G. Hegazy, "Economic Load Dispatch Problem using Particle Swarm Optimization Technique Considering Wind Power Penetration," in 2019 International Conference on Smart Energy Systems and Technologies, pp. 1–6, 2019.

[5] Y. Abdelaziz, E. S. Ali, and S. M. Abd Elazim, "Combined economic and emission dispatch solution using Flower Pollination Algorithm,"International Journal of Electrical Power & Energy Systems, vol. 80, pp. 264–274, 2016.

[6] H. M. Dubey, M. Pandit, B. K. Panigrahi, and M. Udgir, "Economic Load Dispatch by Hybrid Swarm Intelligence Based Gravitational Search Algorithm," International Journal of Intelligent Systems and Applications, vol. 5, no. 8, pp. 21–32, 2013.

[7] R. Vijay, "Intelligent Bacterial Foraging Optimization Technique to Economic Load Dispatch Problem," International Journal of Soft Computing and Engineering, vol. 2, no. 2, pp. 55–59, 2012.

[8] B. S. Serapião, "Cuckoo Search for Solving Economic Dispatch Load Problem," Intelligent Control and Automation, vol. 04, no. 04, pp. 385–390, 2013.

[9] J. Lin and Z.-J. Wang, "Multi-area economic dispatch using an improved stochastic fractal search algorithm," Energy, vol. 166, pp. 47–58, 2019.

[10] M. Ghasemi, J. Aghaei, E. Akbari, S. Ghavidel, and L. Li, "A differential evolution particle swarm optimizer for various types of multi-area economic dispatch problems," Energy, vol. 107, pp. 182–195, 2016.

[11] D. C. Secui, "The chaotic global best artificial bee colony algorithm for the multi-area economic/emission dispatch," Energy, vol. 93, pp. 2518–2545, 2015.

[12] H. Salimi, "Stochastic Fractal Search: A powerful metaheuristic algorithm," Knowledge-Based Systems, vol. 75, pp. 1–18, 2015.

[13] V. Kumar Sharma and B. Kasniya, "Economic Load Dispatch Using Fuzzy Logic Controlled Genetic Algorithms," International Journal of Scientific & Engineering Research, vol. 6, no. 10, pp. 141–149, 2015.

[14] A. Laoufi, A. Hazzab, and M. Rahli, "Economic power dispatch using fuzzy-genetic algorithm," International Journal of Applied Engineering Research, vol. 1, no. 3, pp.409-426, 2006.

[15] M. Afzal and M. K. Madhav, "Economic Load Dispatch and Unit Commitment Solution Using Advanced Optimization approach-A Review," International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering, vol. 6, no. 10, pp. 7587–7593, 2017.

[16] L. Wang and C. Singh, "Environmental/economic power dispatch using a fuzzified multi-objective particle swarm optimization algorithm," Electric Power Systems Research, vol. 77, no. 12, pp. 1654–1664, 2007.

[17] F. A. Mohamed, H. N. Koivo, R. Carriveau, "Modelling and environmental/economic power dispatch of

microgrid using multiobjective genetic algorithm optimization," Fundamental and Advanced Topics in Wind Power, 2011.
[18] L. Singh and J. S. Dhillon, "Interactive fuzzy decision making for multiobjective load dispatch," International Journal of Sustainable Energy, vol. 27, no. 1, pp. 15–27, 2008.
[19] N. Karthik, A. K. Parvathy, and R. Arul, "Multi-objective economic emission dispatch using interior search algorithm," International Transactions on Electrical Energy Systems, vol. 29, no. 1, pp. e2683, 2019.
[20] A. Derghal, N. Golea, and N. Essounbouli, "A fuzzy interval optimization-based approach to optimal generation scheduling in uncertainty environment," Journal of Renewable and Sustainable Energy, vol. 8, no. 6, p. 065501, 2016,
[21] M. Pathak, and K. Y. Pandit, "Combined economic emission dispatch in a micro grid: A comprehensive survey," International Journal of Applied Engineering Research, vol. 12, no. 24, pp. 15876–15901, 2017.
[22] S. Sahoo, K. Mahesh Dash, R. C. Prustya, A. K. Barisala, "Comparative analysis of optimal load dispatch through evolutionaryalgorithms", Ain Shams Engineering Journal, vol 6, no. 1, pp. 107-120, 2015.
[23] E. J. Solteiro Pires, J. A. Tenreiro Machado, P. B. de Moura Oliveira, J. Boaventura Cunha, L. Mendes, "Particle swarm optimization with fractional-order velocity," Nonlinear Dynamics, vol.61, no.1, pp. 295-301, 2010.
[24] R. Eberhart, and J Kennedy, "A new optimizer using particle swarm theory," In: Proceedings of the 6th International Symposium Micro Machine and Human Science (MHS), 1995, pp. 39–43, 1995
[25] B. Pourghebleh, and V. Hayyolalam, "A comprehensive and systematic review of the load balancing mechanisms in the Internet of Things," Cluster Computing, vol. 23, no.2. pp.641-61, 2020.
[26] G. Jayabarathi, V. Sadasivam, T. Ramachandran, "Evolutionary programming-based multiarea economic dispatch with tie line constraints," Electric Machines &Power Systems, vol. 28, no.12, pp.1165-1176, 2000.
[27] J. S. Al-Sumait, J. K. Sykulski, A. K. Al-Othman, "Solution of different types of economic load dispatch problems using a pattern search method," Electric Power Components and Systems, vol. 36, no. 3, pp. 250-265, 2008.
[28] D. N. Jeyakumar, T. Jayabarathi, T. Raghunathan, "Particle swarm optimization for various types of economic dispatch problems," International Journal of Electrical Power & Energy Systems, vol.28, no. 1, pp.36-42, 2006.
[29] M. Sharma, M. Pandit, and L. Srivastava, "Reserve constrained multi-area economic dispatch employing differential evolution with time-varying mutation," International Journal of Electrical Power & Energy Systems vol. 33, no. 3, pp. 753-766, 2011.
[30] N. H. Awad, M. Z. Ali, P. N. Suganthan, E. Jaser, "A decremental stochastic fractal differential evolution for global numerical optimization," Information Sciences, vol.372, pp. 470-91, 2016.
[31] S. Khalilpourazari, and S. Khalilpourazary, "A robust stochastic fractal search approach for optimization of the surface grinding process," Swarm and Evolutionary Computation, vol. 38, pp.173-186, 2018.
[32] S. Rahnamayan, H. R. Tizhoosh, M. M. A. Salama, "Opposition-based differential evolution," IEEE Transactions on Evolutionary Computation, vol. 12, no.1, pp.64-79, 2008.
[33] J. Lin, Z. J. Wang, "Parameter identification for fractional-order chaotic systems using a hybrid stochastic fractal search algorithm," Nonlinear Dynamics, vol. 90, no. 2, pp.1243-1255, 2017.
[34] M. Basu, "Teaching–learning-based optimization algorithm for multi-area economic dispatch," Energy, vol. 68, pp. 21-28, 2014.
[35] B. Pattanaik, and S. Murugan, "Cascaded H-Bridge Seven Level Inverter using Carrier Phase Shifted PWM with Reduced DC sources," International Journal of MC Square Scientific Research, vol. 9, no.3, pp. 30-39, 2017.
[36] N. Manie, and B. Pattanaik, "Zeta DC-DC converter based on MPPT technique for BLDC application," International Journal of MC Square Scientific Research, vol. 11, no.2, pp. 1-12, 2019.