Grasshopper Optimization Algorithm on Combined Economic Emission Dispatch Problem Involving Cubic Functions

Karthikeyan. R, Subramanian. S, Elanchezhian. E. B

Abstract*: *In this paper, grasshopper optimization algorithm is presented to resolve the combined economic emission dispatch (CEED) problem involving cubic functions considering power flow constraints. Electric power system wants to satisfy its customers load demand with minimum fuel cost and emission. Fuel cost and emission has instantly association with energy cost. In CEED problem, the price penalty factor occupies a cardinal role to fetch the optimal results. The various types of price penalty factor available in the literature are analyzed to determine the optimal one for the test cases considered. The test systems used in this CEED problem are 3 unit system considering transmission loss and 13 unit system considering valve point effects. The leading requirement in both the test cases is to optimize the total cost, fuel cost and emission. The numerical and statistical results affirm the high degree of the solution founded by GOA and its superiority is compared with already existing algorithms employed in solving CEED problems.

Keywords*: *CEED, Emission, Fuel cost, Grasshopper Optimization Algorithm, Price penalty factor, Total cost.

I. INTRODUCTION

Electrical power generation systems chiefly depend on fossil fuel powered thermal plants for power generation. The burning up of fossil fuels in the power generation systems ought to be curtailed. Environmental pollution due to the emission of large amount of pollutant gas-particulates is another fact that encourages researchers to work on decreasing the use of fossil fuel in the thermal plants during the process of electricity generation. Although various other types of power generations viz., hydroelectric power generation, nuclear power generation and recent renewable energy methodology have been devised and implemented to produce electricity, thermal power generation with fossil fuel still remains to be the mostly employed to produce power. Thus, the major issue in electricity generation frameworks is Economic Dispatch (ED) problem, which deals with the minimization of generator's fuel cost and the Emission Dispatch (EmD) problem, which deals with the minimization of emission of fossil fuel during power generation. Both this objectives are highly conflicting in nature and cannot be optimized simultaneously. This conflicting objectives brings about the multi-objective optimization problem namely Combined Economic and Emission Dispatch (CEED) problem which minimizes both the emission of hazardous gases, and use of generator fuel simultaneously.

Over the decades, many optimization methods have been employed to find the solution for CEED problem. Artificial intelligence based methods such as Flower Pollination Algorithm (FPA) [1], Hybrid Bat Algorithm (HBA) [2], Enhanced Moth-Flame Optimization (EMFO) [3], Phasor Particle Swarm Optimization (PPSO) [4], Progressive Bounded Constraints-Hybperbolic Smoothing-Modified Logarithmic Barrier Function with Inertia Correction-(PBC-HS-MLBIC) [5], have been employed to find the solution for CEED problem involving quadratic cost functions.

Most of the existing techniques optimize the CEED problem having quadratic cost functions. The most realistic presentation of cost and emission functions of generating stations by higher order polynomials makes the system more realistic and accurate than representing by quadratic functions. A few approaches like Multi-objective Dynamic Economic Dispatch (MODED) [6], Modified Firefly Algorithm (MFA) [7], Simulated Annealing (SA) [8], Novel Bat Algorithm (NBA) [9], Direct Search Method (DSM) [10] and Bacterial Foraging and Nelder-Mead (BF-NM) Algorithm [11] are employed to solve the CEED problem considering more practical higher order cost functions.

The multi-objective CEED problem is converted to single objective function by presenting the price penalty factors. This price penalty factor is used to blend the two odd objectives, cost and emission. The most of the researchers used $h_{max-max}$ price penalty factor [12] to blend the two different objectives. Some of the other price penalty factors such as $h_{min-max}$, $h_{max-min}$, $h_{min-min}$, $h_{average}$ and h_{common} are also used in literature [13, 14] to solve the CEED problem. But all the above penalty factors are seldom used jointly in the same test functions. In this paper, all the above penalty factors are used to blend the cost and emission to find the total cost of the test system and the most suitable h parameter is chosen for optimization.

Often authors have applied their presented methods in various test systems to optimize the CEED problem and have selected the appropriate methods for small and large systems. The holistic review of CEED [15] depicts that the application of naturally inspired metaheuristic approaches outperforms better than the traditional methods to resolve the CEED problem, although the hybrid strategies are seen to be computationally difficult but more potential. Hence a naturally inspired Grasshopper Optimization Algorithm (GOA) [16-18] derived from the swarming conduct of the grasshopper is proposed in this paper to determine the optimal solution for CEED problem with objective functions in the form of cubic equations.

Revised Manuscript Received on October 15, 2019

Karthikeyan. R, Lecturer (Assistant Professor deputed from Annamalai University), Alagappa Government Polytechnic College, Karaikudi, India.

Subramanian. S, Professor, Annamalai University, Annamalainagar, India.

Elanchezhian. E. B, Lecturer (Assistant Professor deputed from Annamalai University), Government Polytechnic College, Srirangam, India.

II. PROBLEM FORMULATIONS

The objective of CEED problem is to minimize the two incompatible objective functions which include fuel cost and emission, satisfying the system's equality and inequality constraints. The problem formulation is as follows:

2.1 Economic Dispatch (ED)

$$F_C = \sum_{i=1}^{N} \left(a_i P_i^3 + b_i P_i^2 + c_i P_i + d_i\right) + \left|e_i \sin(f_i(P_{i,\min} - P_i))\right| \left(\frac{\$}{h}\right) \tag{2.1}$$

where F_C = fuel cost of the generator, P_i = real power generation of unit i, a_i, b_i, c_i, d_i = cost coefficients of generating unit i, e_i, f_i = valve point effect coefficients of generating unit i, and N = number of generating units.

2.2 Emission Dispatch (EmD)

$$E_T = \sum_{i=1}^{N} \left(\alpha_i P_i^3 + \beta_i P_i^2 + \eta_i P_i + \gamma_i\right) \left(\frac{kg}{h}\right) \tag{2.2}$$

where E_T =emission of the generator, P_i= real power generation of unit i, α_i, β_i, η_i, γ_i = emission coefficients of generating for unit i and N = number of generating units.

2.3 Combined economic emission dispatch (CEED)

The price penalty factor h_i converts multi-objective optimization into single objective optimization problem as follows.

$$F_T = \sum_{i=1}^{N} \left(\left(a_i P_i^3 + b_i P_i^2 + c_i P_i + d_i\right) + \left|e_i \sin(f_i(P_{i,\min} - P_i))\right| \right) + h_i\left(\alpha_i P_i^3 + \beta_i P_i^2 + \eta_i P_i + \gamma_i\right) \left(\frac{\$}{h}\right) \tag{2.3}$$

where F_T = total cost of generating units

2.4 Various price penalty factors of CEED's as follows

The six price penalty factors viz., $h_{min\text{-}max}$, $h_{max\text{-}max}$, $h_{max\text{-}min}$, $h_{min\text{-}min}$, $h_{average}$ and h_{common} are applied to solve the CEED problem and are as follows

2.4.1 min-max price penalty factor

$$h_{\min-\max\ i} = \frac{\left(\left(a_i P_{\min}^3 + b_i P_{\min}^2 + c_i P_{\min} + d_i\right) + \left|e_i \sin(f_i(P_{i,\min} - P_i))\right|\right)}{\left(\alpha_i P_{\max}^3 + \beta_i P_{\max}^2 + \eta_i P_{\max} + \gamma_i\right)} \left(\frac{\$}{kg}\right) \tag{2.4}$$

2.4.2 max-max price penalty factor

$$h_{\max-\max\ i} = \frac{\left(\left(a_i P_{\max}^3 + b_i P_{\max}^2 + c_i P_{\max} + d_i\right) + \left|e_i \sin(f_i(P_{i,\min} - P_i))\right|\right)}{\left(\alpha_i P_{\max}^3 + \beta_i P_{\max}^2 + \eta_i P_{\max} + \gamma_i\right)} \left(\frac{\$}{kg}\right) \tag{2.5}$$

2.4.3 max-min price penalty factor

$$h_{\max-\min\ i} = \frac{\left(\left(a_i P_{\max}^3 + b_i P_{\max}^2 + c_i P_{\max} + d_i\right) + \left|e_i \sin(f_i(P_{i,\min} - P_i))\right|\right)}{\left(\alpha_i P_{\min}^3 + \beta_i P_{\min}^2 + \eta_i P_{\min} + \gamma_i\right)} \left(\frac{\$}{kg}\right) \tag{2.6}$$

2.4.4 min-min price penalty factor

$$h_{\min-\min\ i} = \frac{\left(\left(a_i P_{\min}^3 + b_i P_{\min}^2 + c_i P_{\min} + d_i\right) + \left|e_i \sin(f_i(P_{i,\min} - P_i))\right|\right)}{\left(\alpha_i P_{\min}^3 + \beta_i P_{\min}^2 + \eta_i P_{\min} + \gamma_i\right)} \left(\frac{\$}{kg}\right) \tag{2.7}$$

2.4.5 Average price penalty factor

$$h_{average_i} = \frac{h_{\min-\max\ i} + h_{\max-\max\ i} + h_{\max-\min\ i} + h_{\min-\min\ i}}{4} \left(\frac{\$}{kg}\right) \tag{2.8}$$

2.4.6 Common price penalty factor

$$h_{common} = \frac{\sum_{i=1}^{N} h_{avg_i}}{n} \left(\frac{\$}{kg}\right) \tag{2.9}$$

2.5 Constraints

The CEED problem is subject to the following constraints

2.5.1 Power balance constraint

The total power generated should be the equal to sum of the total power demand (P_D) and the power line loss (P_{LOSS}). Thus, the power balance equation is as follows

$$\sum_{i=1}^{N} P_i = P_D + P_{LOSS} \quad (MW) \tag{2.10}$$

The transmission loss is a function of active power generation of each generating unit for a given load demand. The same may realized as follows

$$P_{LOSS} = \sum_{i=1}^{N}\sum_{j=1}^{N} P_i B_{ij} P_j + \sum_{i=1}^{N} B_{oi} P_i + B_{oo} (MW) \tag{2.11}$$

where B_{ij} = elements of the (i-j)th symmetric loss coefficient matrix(B), B_{oi} = loss coefficient vector of ith element and B_{oo} = coefficient of the system constant loss.

2.5.2 Generator operational constraint

The power output of each unit should be within the minimum and maximum generating limits. The generating capacity constraint is as follows

$$P_i^{\min} \le P_i \le P_i^{\max} \tag{2.12}$$

where P_i^{min} = minimum bound value of ith generator and P_i^{max} = maximum bound value of ith generator.

III. GRASSHOPPER OPTIMIZATION ALGORITHM

A scientific progress is achieved through the knowledge and predictions about the nature. Nature is the greatest inspirer which helps to solve problems in every aspects of our life. Many of the algorithms have its source from nature.GOA is an algorithm derived from the swarming conduct of the grasshopper which is abundantly present in nature. The most important act of every creature is to find its food (prey) around its environment. The grasshopper adopt flying mode to move from one place to another place and look for its prey. Two main stages in grasshopper's lifecycle are nymph and adult. In nymph stage the insect move slowly and cover limited distance and in adult stage the insect move abruptly and cover large area. In both the stage, grasshopper attempts to explore the prey and then exploit the prey. The experimentation of GOA algorithm is availed from the grasshopper swarming behavior and its method of ensnaring its prey.

Optimization is an enormous defending method to discover solution for many scientific and technical problems. In the process of creating an algorithm a particular problem is solved by processing the date through computer or mathematical operations. The invented idea can be applied upon machine to get the expected results. GOA is an identifiable algorithm and the best solutions are accomplished through recommendable search agents. The searching techniques of the grasshopper are drawn and the population of grasshopper is used to select the search agents.

The mathematical model employed

$$X_i = S_i + G_i + A_i \tag{3.1}$$

where Xi = position of the ith grasshopper, Si = social interaction, Ai = wind advection and Gi = gravity force of the ith grasshopper.

$$S_i = \sum_{\substack{j=1 \\ j \ne i}}^{N} s\left(d_{ij}\right) \hat{d}_{ij} \tag{3.2}$$

where $\hat{d}_{ij}$ = distance between the ith and jth grasshopper,

The social interaction (Si) module is calculated as follows

$$s(r) = f_i e^{\frac{-r}{l}} - e^{-r} \tag{3.3}$$

where f = intensity of attraction, l = attractive length scale

The next essential feature in swarming performance is the social attraction which involves attraction and repulsion of grasshopper, when they move together and apart in the searching space. The parameters *l* and *f* changes the attraction region, repulsion region, and comfort zone importantly [16,17,18]. The function S will explicitly segregate the space between attraction region, comfort zone, and repulsion region and this function returns the value nearer to zero with distance greater than 10.

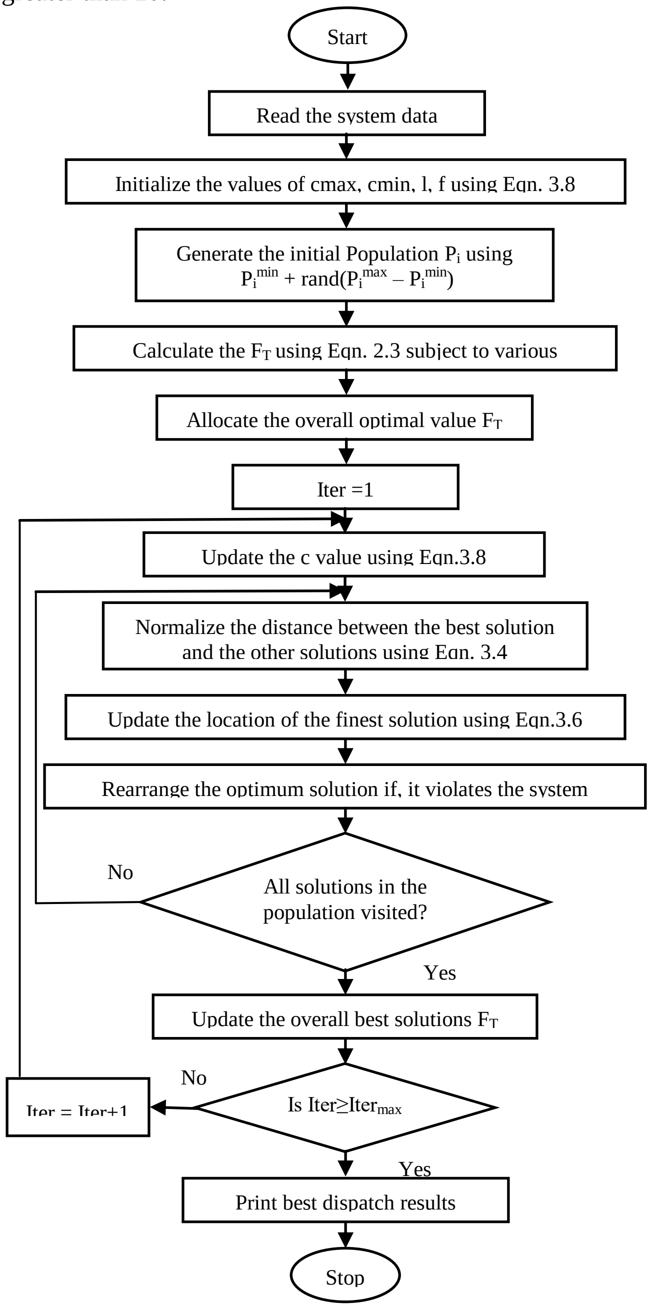

Fig. 1 GOA Implementation for CEED problem

The wind advection (A_i) module is calculated

$$A_i = u\hat{e}_w \tag{3.4}$$

where u = constant drift, $\hat{e}_w$ = unity vector in the wind's direction.

The gravity force (G_i) module is calculated as follows

$$G_i = -g\hat{e}_g \tag{3.5}$$

where g = gravitational constant, $\hat{e}_g$ = unity vector towards the centre of earth.

The S_i, A_i and G_i values substituting the Eqn. (3.1), and to extended as follows:

$$X_i = \sum_{\substack{j=1 \\ j\neq i}}^{N} s\left(\left|x_j - x_i\right|\right)\frac{x_j - x_i}{d_{ij}} - g\hat{e}_g + u\hat{e}_w \tag{3.6}$$

where s(r) = social force and N = number of grasshoppers.

The experiment is undergone until the grasshopper form a single organized swarm. The behaviour is freeze when they reach the comfort zone. The observation of the mathematical model can't be used directly because either the grasshoppers rapidly arrive at the comfort zone or the swarms are not move towards particular point. Further the equation is implicit as follows to solve the optimization problem.

$$X_i^d = c\left(\sum_{\substack{j=1 \\ j\neq i}}^{N} c\frac{ub_d - lb_d}{2} s\left(\left|x_j^d - x_i^d\right|\right)\frac{x_j - x_i}{di_j}\right) + \hat{T}_d \tag{3.7}$$

The coefficient c minmizes the comfort zone proportional to the iteration count and is computed as,

$$c = c_{max} - l\frac{c_{max} - c_{min}}{L} \tag{3.8}$$

where c_{max} = maximum value, c_{min} = minimum value, *l* = current iteration, L = maximum number of iterations

The meticulous effort put up to integrate optimization and GOA is highly successful. Both repulsion and attraction criterion have naturally explore the search space and exploit the promising region respectively. The Fig. 1repesentes the implementation flow diagram for CEED problem.

IV. NUMERICAL SIMULATION RESULTS AND DISCUSSIONS

A simulation study is performed to validate the possibility and effectiveness of the proposed GOA algorithm for the solution of CEED problem through the analysis of following two test cases.

Test case 1: *3 unit system*

Scenario 1: ED neglecting transmission loss
Scenario 2: ED with transmission loss
Scenario 3: EmD neglecting transmission loss
Scenario 4: EmD with transmission loss
Scenario 5: CEED ignoring transmission loss
Scenario 6: CEED with transmission loss.

Test case 2: *13 unit system*

Scenario 7: Emission Dispatch
Scenario 8: Combined economic emission dispatch.

The detailed data of the test case 1 and test case 2 are extracted from [10] and [11] respectively. The CEED problem is being analyzed by 100 iterations on a Core i5, 2.65GHz PC with 4 GB RAM. The Matlab 7.10 platform is used for the implementation of the proposed GOA code.

To realize the best total cost, CEED problem is tested with six different price penalty factors and their effect on cost minimization process is analyzed to fetch the most optimal 'h' parameter for the both test case studies. Further, the performance of GOA is compared with various optimization algorithms.

4.1 Test case 1: 3 unit system

In this test case, three unit system involving cubic cost functions is considered. The input data of generating units viz., generator limit values, fuel cost coefficients, emission coefficients and transmission loss coefficients are taken from [10]. Six different types of scenarios are discussed in this test system.

Scenario 1: ED neglecting transmission loss

In this scenario, the proposed GOA is employed for fuel cost minimization excluding the transmission loss for different load demands like 400MW, 500MW and 600MW. The corresponding generating unit's outputs and fuel cost and emission values are indicated in Table 1.

Table 1: ED results of 3 unit system neglecting transmission loss

		400 MW	500 MW	600 MW
GOA	P_1	52.96	67.97	101.48
	P_2	75.00	81.56	123.52
	P_3	272.04	350.47	375.00
	E_T (kg/h)	373.76	628.17	796.65
	F_C ($/h)	30708.68	44772.99	66173.00
WOA	F_C ($/h)	30721.29	44786.58	66189.38

The minimum fuel cost value for the 400MW, 500 MW and 600MW is 30708.68($/h), 44772.99($/h) and 66173.00($/h) and corresponding emission values are 373.76(kg/h), 628.17(kg/h) and 796.65(kg/h) respectively. The proposed GOA method is compared with the whale optimization algorithm (WOA) results and it is found comparatively less than WOA. The convergence characteristics of variations of fuel cost against iterations for 600MW load demand in 3 unit system is represented in the Fig.2.

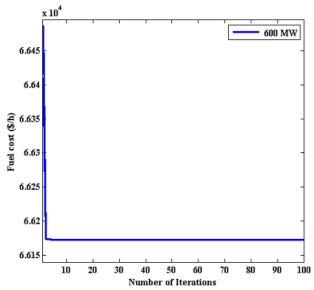

Fig. 2 Convergence characteristics of 3 unit system during ED neglecting transmission loss

Scenario 2: ED with transmission loss

In this section, the 3unit system including transmission loss is taken for different load demands like 400MW, 500MW and 600MW to find the optimal results. The generating unit power output, fuel cost, emission and transmission loss is available in Table 2.

Table 2: ED results of 3 unit system with transmission loss

		400 MW	500 MW	600 MW
GOA	P_1	50.00	67.23	106.58
	P_2	75.00	84.17	134.42
	P_3	281.40	358.97	375.00
	P_L(MW)	6.40	10.37	16.00
	E_T(kg/h)	395.51	660.05	818.19
	F_C($/h)	31496.93	46499.32	71296.79
WOA	F_C($/h)	31507.47	46512.58	71318.37

The minimum fuel cost value for the 600MW is 71296.79 ($/h) and corresponding emission value is 818.19 (kg/h). The transmission loss during the execution is 16.00MW. The fuel cost value got from the GOA method is minimum when compared with other algorithms.

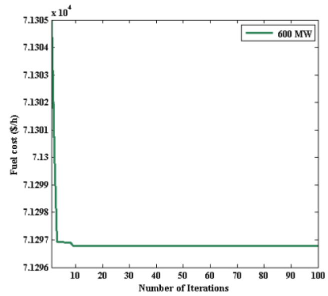

Fig. 3 Convergence characteristics of 3 unit system during ED with transmission loss

The Fig. 3 indicates the convergence characteristics of the variations of fuel cost against 100 iterations for 600MW load demand.

Scenario 3: EmD neglecting transmission loss

The scenario explores the emission minimization optimization process neglecting transmission loss for the different load demands 400MW, 500MW and 600MW by the proposed GOA technique. The corresponding emission values for the above load demands are 289.58 (kg/h), 431.02(kg/h) and 622.04(kg/h) and the fuel cost values are 36910.27($/h), 71546.81($/h) and 109354.51($/h) respectively and are compared with WOA method in Table 3. The obtained results clearly prove the superiority of the proposed algorithm. The Fig. 4 represents convergence characteristics of 3 unit system for emission minimization process neglecting loss for a demand of 600MW.

Table 3: EmD results of 3 unit system neglecting transmission loss

		400 MW	500 MW	600 MW
GOA	P_1	87.70	145.66	175.00
	P_2	112.30	147.72	177.58
	P_3	200.00	206.62	247.42
	F_C($/h)	36910.27	71546.81	109354.51
	E_T(kg/h)	289.58	431.02	622.04
WOA	E_T(kg/h)	302.27	443.84	637.29

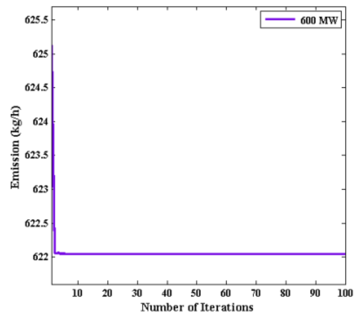

Fig. 4 Convergence characteristics of 3 unit system during EmD neglecting transmission loss

Scenario 4: EmD with transmission loss

This scenario examines the emission minimization process of 3 unit system considering transmission loss. The three different types of load demands are taken to evaluate the emission minimization process and the obtained values of emission minimization using GOA algorithm is compared with WOA and are listed in Table 4. The emission value for 600MW load demand is 660.97(kg/h), transmission loss value is 17.25MW and fuel cost value is 115295.06($/h).

Table 4: EmD results of 3 unit system with transmission loss

		400 MW	500 MW	600 MW
GOA	P_1	91.07	148.83	175.00
	P_2	116.19	152.31	186.21
	P_3	200.00	210.79	256.04
	F_C($/h)	38772.89	75635.11	11529.51
	P_L(MW)	07.26	11.93	17.25
	E_T(kg/h)	297.84	451.50	660.97
WOA	E_T(kg/h)	314.49	473.71	678.27

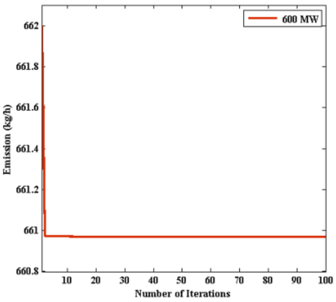

Fig. 5 Convergence characteristics of 3 unit system during EmD with transmission loss

The remaining load demands are 400MW and 500MW and its corresponding emission value is 297.84(kg/h) and 451.50(kg/h). The variations of emission values against 100 iterations for the 600MW load demand are depicted as convergence characteristics in Fig. 5.

Scenario 5: CEED ignoring transmission loss

The combined economic emission dispatch problem is considered in this scenario. The three different load demands of 400 MW, 500 MW and 600 MW are taken to evaluate the total fuel cost neglecting transmission loss. The simulation results of the CEED problem considering 6 different penalty factors are listed in Table 5 for three different load demands.

The Table 5 shows the real power output of the 3 generating units, fuel cost, emission values and total cost. In the CEED considering various penalty factors, the minimum total cost value obtained for the demand of 600MW is **82796.46** ($/h) considering min-max price penalty factor. The corresponding fuel cost and emission generated is **66181.95** ($/h) and **796.61** (kg/h) respectively. From the Table 5 it is also observed that for the other two demands viz., 400MW and 500MW, the optimal minimum total fuel cost is achieved while considering min-max price penalty factor, which clearly depicts the suitability of min-max penalty factor for CEED problems.

Table 5: CEED results of 3 unit system neglecting loss considering various price penalty factors

P_D (MW)	Price penalty Factor	P_1 (MW)	P_2 (MW)	P_3 (MW)	F_C ($/h)	E_T (kg/h)	F_T ($/h)
400	$h_{min-max}$	62.22	75.00	262.78	30851.51	358.39	38346.04
	$h_{max-max}$	50.00	75.00	275.00	30722.56	378.95	66833.30
	$h_{max-min}$	50.00	75.00	275.00	30723.56	378.95	209705.10
	$h_{min-min}$	75.15	84.44	240.41	32083.84	326.42	64844.01
	$h_{average}$	50.00	75.00	275.00	30724.56	378.95	95632.40
	h_{common}	65.32	81.67	253.01	31265.91	342.75	42882.95
500	$h_{min-max}$	77.50	92.34	330.16	45223.49	575.62	57161.84
	$h_{max-max}$	62.15	89.35	348.50	44912.54	621.34	98197.89
	$h_{max-min}$	50.57	83.93	365.50	45324.31	670.20	301719.21
	$h_{min-min}$	95.20	102.46	302.34	47513.63	517.86	98382.55
	$h_{average}$	64.40	88.65	346.95	44866.58	617.36	140754.80
	h_{common}	81.62	100.16	318.22	45923.14	548.36	64508.90
600	$h_{min-max}$	102.90	122.10	375.00	66181.95	796.61	82796.46
	$h_{max-max}$	101.03	123.97	375.00	66173.88	796.68	143481.22
	$h_{max-min}$	105.81	119.19	375.00	66255.75	796.69	449737.72
	$h_{min-min}$	114.29	120.73	364.98	67857.92	771.33	142703.20
	$h_{average}$	105.11	119.89	375.00	66231.05	796.66	204810.09
	h_{common}	101.64	123.36	375.00	66173.12	796.65	93174.39

Table 6: Comparison of CEED results of 3 unit system considering varies price penalty factors for PD=600MW

ED Solution	Min - Max	Max - Max	Max- Min	Min - Min	Average	Common
Fuel cost (F_C)($/h)	100 %	99.87%	100.11%	102.53%	100.07%	99.99%
Emission(E_T)(kg/h)	100%	99.98%	100.04%	96.82%	100.03%	100.02%
Total cost(F_T) ($/h)	100 %	173.11%	543.18%	172.35V	247.37%	112.53%

Among various penalty factors considered, the min-max penalty factor value is considered as base value of 100% and the variation of fuel cost, emission and total cost while considering other penalty factors are suitably compared in terms of percentage in Table 6. It is observed that in the proposed GOA methodology, while considering min-max penalty factor the value of total cost is optimum and while considering max-max penalty factor the value of fuel cost is optimum. Further in CEED minimization problem, the minimized emission is achieved while considering the min-min penalty factor.

The Fig. 6 illustrates the variations of total cost for various price penalty factors during different load demands of 3unit system.

The convergence process of the best solution for total cost achieved by the proposed GOA is illustrated in Fig. 7. The robustness curve involving 100 independent trials by GOA for CEED of 3 unit system is illustrated in Fig. 8.

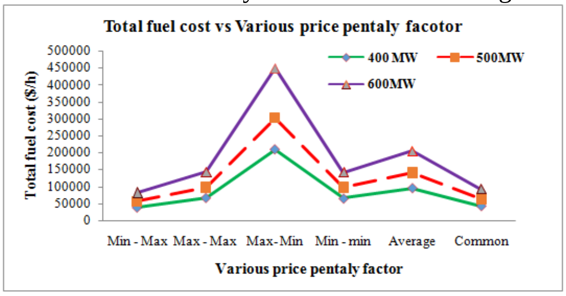

Fig. 6 Total cost versus price penalty factors for 3 unit CEED neglecting loss

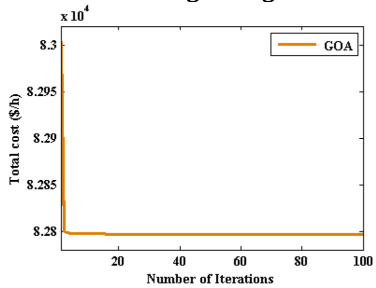

Fig. 7 Convergence characteristics of GOA based CEED of 3 unit system without loss

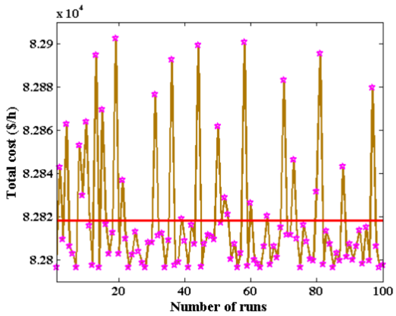

Fig. 8 Roboustness characteristics of GOA based CEED of 3 unit system without loss

Scenario 6: CEED with transmission loss

The CEED of 3 unit system considering transmission loss for 3 different load demands of 400MW, 500MW and 600MW are carried out in this scenario.

The simulation results of the CEED problem considering 6 different penalty factors are listed in Table 7.

Table 7 shows the real power output of the 3 generating units, fuel cost, emission, total cost and losses. In the CEED considering various penalty factors, the minimum total cost obtained for the demand of 600MW is **88384.45** ($/h) while considering min-max price penalty factor. The corresponding values of fuel cost, emission and loss evaluated by the GOA are **71266.57** ($/h) **817.58** (kg/h) and **15.91** (MW) respectively.

Further, the Table 8 expresses the simulation results of CEED problem considering various penalty factors. The values are taken from min-max penalty factor having a basis of 100%. It is observed that in the proposed GOA the value of total cost is optimum while considering min-max penalty factor and the value of fuel cost is optimum while considering max-max penalty factor. The value of transmission loss is optimum in min-min penalty factor.

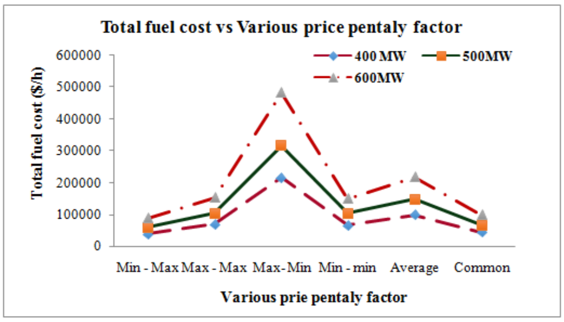

Fig. 9 Total cost versus price penalty factors for 3 unit CEED with loss

The Fig.9 shows the variations of total cost for various price penalty factors during different load demands of 3 unit system.

Table 7: CEED results of 3 unit system with loss considering various price penalty factors

P_D (MW)	Price penalty factor	P_1 (MW)	P_2 (MW)	P_3 (MW)	F_C ($/h)	E_T (kg/h)	F_T ($/h)	P_L (MW)
400	$h_{min-max}$	64.33	76.81	266.21	31824.06	369.93	39548.63	7.35
	$h_{max-max}$	50.00	75.92	281.84	31660.71	397.18	68911.61	7.76
	$h_{max-min}$	50.00	75.00	282.78	31667.33	399.17	215568.32	7.78
	$h_{min-min}$	77.61	86.14	243.08	33129.09	335.69	66822.32	6.83
	$h_{average}$	50.00	76.14	281.62	31692.60	396.70	98625.20	7.76
	h_{common}	67.46	83.62	256.06	32260.37	352.93	44222.39	7.14
500	$h_{min-max}$	80.60	95.38	335.65	47291.46	599.54	59729.23	11.63
	$h_{max-max}$	66.03	92.12	354.08	46933.14	646.94	102700.22	12.23
	$h_{max-min}$	55.15	86.31	371.33	47293.86	697.71	315981.88	12.79
	$h_{min-min}$	98.84	105.21	306.74	49759.31	537.84	102635.35	10.79
	$h_{average}$	68.62	91.23	352.31	49888.14	642.23	147187.45	12.16
	h_{common}	84.80	103.18	323.31	48032.33	570.70	67375.33	11.29
600	$h_{min-max}$	110.64	130.27	375.00	71266.57	817.58	88384.45	15.91
	$h_{max-max}$	109.71	131.21	375.00	71256.36	817.67	153625.03	15.92
	$h_{max-min}$	115.77	125.08	375.00	71471.50	817.50	482270.29	15.85
	$h_{min-min}$	119.35	124.79	371.58	72152.13	808.81	150760.27	15.72
	$h_{average}$	114.32	126.55	375.00	71387.59	817.45	218857.76	15.87

	h_{common}	109.44	131.49	375.00	71259.93	817.70	98969.60	15.93

Table 8: Comparison of CEED results of 3 unit system with loss considering varies price penalty factors for P_D=600MW

ED Solution	Min - Max	Max - Max	Max- Min	Min - Min	Average	Common
Fuel cost (F_C)($/h)	100 %	99.98 %	100.28%	101.24%	100.17%	99.99 %
Emission(E_T) kg/h)	100 %	107.90%	116.37 %	89.70%	107.12 %	95.19 %
Total cost(F_T) ($/h)	100 %	173.81%	545.65 %	170.57 %	247.62 %	111.97%
Loss (P_L) (MW)	100 %	100.06%	99.62%	98.80 %	99.74 %	100.12 %

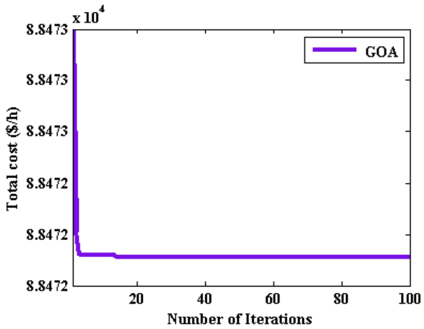

Fig. 10 Convergence characteristics of GOA based CEED of 3 unit system with loss

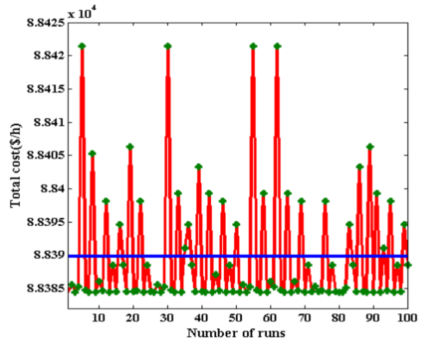

Fig. 11 Robustness characteristics of GOA based CEED of 3 unit system with loss

In the convergence process the best solution for total cost achieved by the proposed GOA is illustrated in Fig.10. The robustness curve for 100 independent trials by GOA is illustrated in Fig.11.

4.2 Test case 2: 13 unit system

A system of 13 generators, involving valve point effects is examined in this case. The system input data is adapted from [11]. The 3 different types of load demands 1700MW, 1800MW and 1900MW are considered.

Scenario 7: Emission Dispatch

In this scenario, emission minimization of 13 unit system for 3 different load demands are taken and tested. The values of minimum emission are 5179.33(kg/h), 6457.01(kg/h) and 7804.48(kg/h) respectively for 1700MW, 1800MW, and 1900MW.

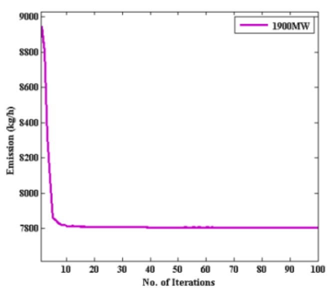

Fig. 11 Convergence characteristics of 13 unit during EmD

Table 9: EmD results of 13 unit system

		1700MW	1800MW	1900MW
GOA	P_1	95.99	101.03	107.81
	P_2	91.27	96.14	102.72
	P_3	91.18	96.19	102.72
	P_4	156.61	165.43	200.00
	P_5	156.11	165.37	176.96
	P_6	156.97	165.00	176.61
	P_7	156.54	165.59	176.51
	P_8	157.72	165.25	176.67
	P_9	157.61	200.00	200.00
	P_{10}	120.00	120.00	120.00
	P_{11}	120.00	120.00	120.00
	P_{12}	120.00	120.00	120.00
	P_{13}	120.00	120.00	120.00
	F_C($/h)	18149.25	19318.81	20664.15
	E_T(kg/h)	5179.33	6457.01	7804.48
WOA	E_T(kg/h)	5294.38	6533.18	7840.04

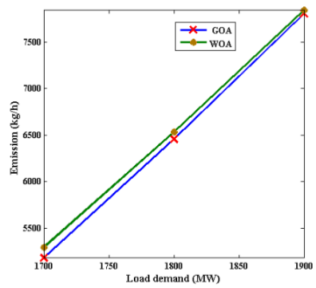

Fig. 12 Comparison characteristics of 13 unit system during EmD

. The dispatch values of each generating units, emission and fuel cost values during EmD process are available in the Table 9. The emission fetched by GOA method is comparatively less to WOA method. The convergence characteristics of variations of emission against iterations for the load demand of 1900MW in 13 unit system is represented in the Fig. 12 and Fig. 13 shows the comparison of emission values fetched by different algorithm methods.

Scenario 8: Combined economic emission dispatch

The CEED of 13 unit system using GOA are carried out considering four different price penalty factors such as $h_{min-max}$, $h_{max-max}$, $h_{average}$ and h_{common}. The CEED results by GOA are available in Table 10. In CEED minimization process the least total cost achieved for the demand of 1900MW is 19810.89 ($/h) while blending emission and fuel cost by min-max penalty factor. The corresponding fuel cost and emission yielded by the GOA are 18914.38($/h) and 42811.04 (kg/h). The other two more load demands are 1700MW and 1800MW and its corresponding minimum total cost are 17523.32 ($/h) and 18572.16 ($/h) achieved while considering min-max penalty factor.

Table 10: CEED results of 13 unit system considering various price penalty factors

P_D	1700MW				1800MW				1900MW			
Price penalty factor	$h_{min-max}$	$h_{max-max}$	$h_{average}$	h_{common}	$h_{min-max}$	$h_{max-max}$	$h_{average}$	h_{common}	$h_{min-max}$	$h_{max-max}$	$h_{average}$	h_{common}
P_1	538.56	359.04	625.95	89.76	627.00	448.80	448.80	179.52	628.32	448.80	538.56	93.19
P_2	299.52	216.12	224.39	84.35	299.20	149.79	296.74	149.67	224.41	224.45	224.30	149.60
P_3	299.50	224.30	224.39	83.02	299.18	224.40	224.33	149.60	299.97	224.56	295.10	97.85
P_4	60.00	99.04	60.00	165.92	60.00	104.67	101.86	112.05	113.60	112.23	107.65	200.00
P_5	70.99	109.47	109.27	200.00	60.00	114.09	110.14	111.82	60.00	110.17	106.89	159.86
P_6	60.00	100.60	60.00	117.05	60.00	110.04	60.00	113.13	60.00	110.15	109.82	159.77
P_7	60.00	109.63	60.00	159.74	60.00	137.08	109.61	200.00	109.86	112.03	107.70	159.73
P_8	60.00	109.77	60.00	160.43	60.82	111.73	60.00	161.18	153.84	117.66	109.83	200.00
P_9	60.00	106.74	60.00	159.73	83.80	110.15	156.69	160.62	60.00	159.75	103.36	200.00
P_{10}	40.00	64.54	66.00	120.00	40.00	77.29	74.42	115.19	40.00	51.79	40.00	120.00
P_{11}	40.00	70.70	40.00	120.00	40.00	40.00	47.41	120.00	40.00	76.81	46.79	120.00
P_{12}	56.43	75.05	55.00	120.00	55.00	85.79	55.00	120.00	55.00	64.20	55.00	120.00
P_{13}	55.00	55.00	55.00	120.00	55.00	86.17	55.00	107.22	55.00	87.40	55.00	120.00
F_C ($/h)	17251.11	17673.14	17264.43	18055.77	18152.60	18376.38	18198.46	18614.69	18914.38	19167.18	19008.23	19868.30
E_T (kg/h)	36174.89	16937.34	38508.67	17385.47	44947.79	21527.44	26454.71	23111.37	42811.04	23987.48	33713.98	24405.76
F_T ($/h)	**17523.32**	**22463.26**	**20933.00**	**19897.28**	**18572.16**	**24826.68**	**22169.12**	**21388.30**	**19810.89**	**26593.49**	**23416.13**	**22639.99**

Table 11: Comparison of CEED results of 13 unit system considering varies price penalty factors for PD=1900MW

ED Solution	Min - Max	Max - Max	Average	Common
Fuel cost (F_C)($/h)	100%	101.33%	100.49%	105.04%
Emission(E_T) (kg/h)	100%	56.03%	78.75%	57.01%
Total cost(F_T) ($/h)	100%	134.23%	118.19%	114.28%

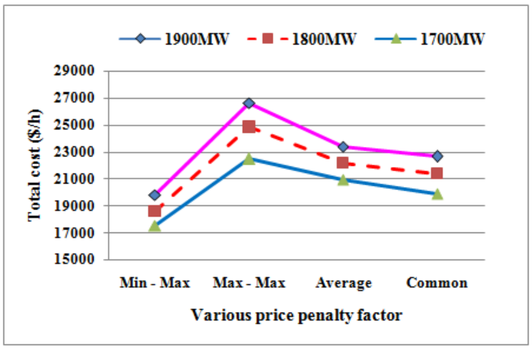

Fig. 14 Total cost versus various price penalty factors of 13 unit system

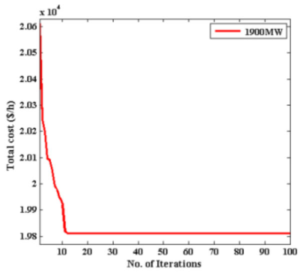

Fig. 15 Convergences characteristics of 13 unit system

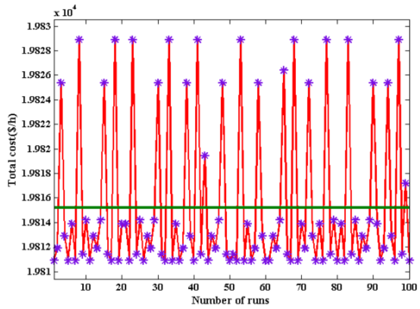

Fig. 16 Robountess characteristics of 13 unit system

The Fig. 13 shows the variations of total cost for various price penalty factors during different load demands of 13 unit system. The convergence process for the best solution of total cost achieved by the proposed GOA is illustrated in Fig. 14. The robustness curve for 100 independent trials of GOA is illustrated in Fig. 15.

4.3 Comparative and Performance analysis

GOA is an impressive mechanism which is implemented in these two test cases. The prime aim is to find the optimum total cost

In test case 1 six price penalty factors are taken for testing process. It is evaluated that only in min-max price penalty factors the total cost value is minimum. In the test case 2 four price penalty factors is tested and among them only in min-max price penalty factors the total cost value is optimum. Thus in both the test cases the optimum values are achieved in min-max price penalty factors. These two test case values are compared with WOA method and the total cost values are lesser than the WOA. Table 12 shows the comparison of total cost achieved with WOA.

In the Performance analysis of best feasible solution by GOA for 2 different test cases, the minimum cost, maximum cost and average cost are achieved after 100 independent runs. The analysed values are listed in Table 13. In CEED problem using GOA the values of solution iteration for all the cases are achieved at fast convergence. The success rate and the solution iteration are proficient which makes the proposed algorithm much superior than other heuristic techniques.

The Table 11 shows the simulation results of CEED problem assuming the results obtained by min-max price penalty factor as base value of 100%. The deviation of other values against this base value is also illustrated in Table 11. It is observed that the total cost and fuel cost gets its minimum value when min-max penalty factor is considered in GOA method. The minimum emission value is achieved while considering the max-max penalty factor.

Table 12: Comparison of simulation results for each test case

	Min – Max	Max - Max	Max- Min	Min - Min	Average	Common
Test case-1: 3 unit system without loss (P_D=600MW)						
GOA	**82796.46**	143481.24	449737.72	142703.20	204810.09	93174.39
WOA	83465.25	144702.13	453695.45	143708.09	206510.31	93867.74
Test case-1: 3 unit system with loss(P_D=600MW)						
GOA	**88384.45**	153625.03	482270.29	150760.27	218857.76	98969.60
WOA	89213.12	155013.08	486702.91	151860.59	221780.59	99968.64
Test case-2: 13 unit system (P_D=1700MW)						
GOA	**17523.32**	22463.26	-	-	20933.00	19897.28
WOA	17583.62	22472.05	-	-	20982.83	19926.22
Test case-2: 13 unit system (P_D=1800MW)						
GOA	**18572.16**	24826.68	-	-	22169.12	21388.30
WOA	18647.48	24879.64	-	-	22237.64	21438.92
Test case-2: 13 unit system (P_D=1900MW)						
GOA	**19810.89**	26593.49	-	-	23416.13	22639.99
WOA	19902.74	26648.34	-	-	23546.72	22694.63

Table 13: Performance analysis of best feasible solution by GOA for 2 different test cases

S. no		Test Case 1		Test Case 2
		without loss	with loss	
1.	Demand	600 MW	600MW	1900 MW
2.	Optimal h parameter	Min-Max	Min-Max	Min-Max
3.	Solution iteration	14	15	14
4.	Minimum cost ($/h)	82796.46	88384.45	19810.89
5.	Average cost ($/h)	82818.22	88389.74	19815.23
6.	Maximum cost ($/h)	82902.54	88421.45	19828.91
7.	Success rate	76	73	78

V. CONCLUSION

In this work, GOA algorithm is applied effectively on test systems involving cubic cost functions to solve the ED, EmD and CEED. In CEED problem, different price penalty factors are applied in both the test cases to find the optimal total cost. All the scenarios in test cases are executed independently and the results fetched while considering different penalty factors are recorded and the best result giving factor is recognized as most feasible price penalty factor. From the obtained results, it is observed that the min-max penalty approach is more optimal compared to other factors in fetching minimum total cost in the both the test cases considered. Further the results obtained GOA; in comparison with WOA method is least in all the scenarios explored, which clearly portrays the suitability of GOA for CEED problems with objective functions in the form of cubic equations.

ACKNOWLEDGMENT

The authors acknowledge with gratitude for the support and facilities provided by the authorities of Annamalai University, India to carry out this research work.

REFERENCES

1. A.Y. Abdelaziz, E.S. Ali and S.M. Abd Elazim, “Implementation of flower pollination algorithm for solving economic load dispatch and combined economic emission dispatch problems in power systems”, Energy, Vol. 101, (2016), pp. 506-518.
2. Huijun Liang, Yungang Liu, Fengzhong Li and Yanjun Shen, “A multi-objective hybrid bat algorithm for combined economic/emission dispatch”, Electrical Power and Energy Systems, vol. 101, (2018), pp. 103-115.
3. Asmaa. A, Elsakaan, Ragab A. El-Sehiemy, Sahar S. Kaddah and Mohammed I. Elsaid, “An enhanced moth-flame optimizer for solving non-smooth economic dispatch problems with emissions”, Energy, vol.157, Aug., (2018), pp. 1063-1078.
4. Maedeh Gholamghasemi, Ebrahim Akbari, Mohammad Bagher Asadpoor and Mojtaba Ghasemi, “A new solution to the non-convex economic load dispatch problems using phasor particle swarm

optimization", Applied soft computing, vol. 79, June, (2019),pp.111-124.
5. Elis Gonçalves, Antonio Roberto Balbo, Diego Nunes da Silva, Leonardo Nepomucenoa, Edmea Cassia Baptistab and Edilaine Martins Solerb, "Deterministic approach for solving multi-objective non-smooth Environmental and Economic dispatch problem", International Journal of Electrical Power and Energy Systems, vol. 104, Jan., (2019), pp. 880-897.
6. Moses Peter Musau, Nicodemus Odero Abungu and Cyrus Wabuge Wekesa, "Multi Objective Dynamic Economic Dispatch with Cubic Cost Functions", International Journal of Energy and Power Engineering, (2015), vol. 4, no. 3, pp. 153-167.
7. Moses Peter Musau, N. O. Abungu and C.W. Wekesa, " Single objective dynamic economic dispatch with cubic cost functions using a hybrid of modified firefly algorithm with levy flights and derived mutations", International journal of engineering research & technology, vol. 5, no. 5, (2016), pp. 364-370.
8. Ismail Ziane and Farid Benhamida, " Solving the generation scheduling with cubic fuel cost function using simulated annealing", International Journal of Energy, Information and Communications, vol. 7, no. 2, (2016), pp.1-8.
9. Fahad Parvez Mahdi, Pandian Vasant, Vish Kallimani and M. Abdullah-Al-Wadud, "Comparative study to solve emission dispatch problem using novel bat algorithm considering cubic function and transmission loss", Journal of Applied Environmental and Biological Sciences, vol. 7, (2017), pp. 22-27.
10. Ganesan.S and Subramanian.S, "Non-convex economic thermal power management with transmission loss and environmental factors: Exploration from direct search method," International Journal of Energy Sector Management, vol. 6, no. 2, (2012), pp.228-238.
11. Rahmat-Allah Hooshmand, Moein Parastegari and Mohammad Javad Morshed, "Emission, reserve and economic load dispatch problem with non-smooth and non-convex cost functions using the hybrid bacterial foraging-Nelder–Mead Algorithm", Applied Energy, vol. 89, (2012), pp. 443-453.
12. Dimitrios Gonidakis and Aristidis Vlachos, "A new sine cosine algorithm for economic and emission dispatch problems with price penalty factors", Journal of Information and Optimization Sciences, vol. 40, no. 3, Apr., (2019), pp.679-697.
13. Narges Daryani, Kazem Zare, "Multiobjective power and emission dispatch using modified group search optimization method" Ain shams engineering journal, vol. 9, no. 3, Sep., 2018, pp.319-328.
14. Hemanshu C. Mahla, R. H. Bhesdadiya, Pradeep Jangir and I. N. Trivedi, " Combined economic emissions dispatch problem using lagrange's method" International journal of advance engineering and research development , Vol. 2, No. 5, May, 2015, pp.319-326.
15. Fahad Parvez Mahdi, Pandian Vasant, Vish Kallimani, Junzo Watada, Patrick Yeoh Siew Fai, M. Abdullah-Al-Wadud, "A holistic review on optimization strategies for combined economic emission dispatch problem", Renewable and sustainable energy, (2018), vol. 81, pp. 3006-3020.
16. Shahrzadsaremi, Seyedalimirjalili and Andrew lewis, "Grasshopper optimization algorithm: Theory and application", Advances in Engineering Software, vol. 105, (2017), pp. 30-47.
17. Majdi Mafarja, Ibrahim Aljarah, Ali Asghar Heidari, Abdelaziz I. Hammouri , Hossam Faris , Ala' M. Al-Zoubi and Seyedali Mirjalili, "Evolutionary population dynamics and grasshopper optimization approaches for feature selection problems", Knowledge-Based Systems, (2017), pp. 1-21.
18. Touqeer Ahmed Jumani, Mohd Wazir Mustafa, Madihah Md Rasid, Nayyar Hussain Mirjat, Zohaib Hussain Leghari and M. Salman Saeed, "Optimal Voltage and Frequency Control of an Islanded Microgrid Using Grasshopper Optimization Algorithm", Energies, vol. 11, no. 11, (2018), pp. 1-20.

AUTHORS PROFILE

R. Karthikeyan is currently Lecturer (Assistant professor on deputation from Annamalai University), Department of EEE, Alagappa government polytechnic college, Karaikudi, Tamilnadu. He has been teaching Diploma, UG & PG classes well over 11 years. His research interests include power system operations and control.

Dr. S. Subramanian is currently professor, Department of EEE at Annamalai University, Chidambaram, Tamilnadu. He has been teaching UG & PG classes well over two decades. He has to his credit more than 125 research articles of which most of the papers are SCI/Scopus Indexed. He is a senior member in IEEE, ISTE and IOE.

Dr. E. B. Elanchezhian is currently Lecturer (Assistant professor on deputation from Annamalai University), Department of EEE, Government polytechnic college, Srirangam, Tamilnadu. He has done Ph.D at Annamalai University in 2016. He has been teaching Diploma, UG & PG classes well over 12 years. He has to his credit 19 research papers of which 6 papers are SCI/Scopus Indexed. He is a senior member in IEEE, ISTE & IOE.