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Solution of Multi Objective Environmental Economic Dispatch by Grey Wolf Optimization Algorithm

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Abstract: This paper presents the recently developed Grey Wolf Optimization (GWO) algorithm, which is based on the food collecting behavior of grey wolves to determining the feasible optimal solution of the multi objective environmental economic dispatch (MOEED) problem. Nonlinear characteristics of alternators and exponential emissions and loss minimization are considered in the problem. While searching for a better solution, GWO does not require any statistics about the gradient of the objective function. The GWO algorithm effectiveness has been tested on four different systems as 6-unit (IEEE 30-bus), 10-unit, 11-unit and 14-unit (IEEE 118-bus) test systems to solve the MOEED problems. The result of the test systems shows, for practical power systems GWO as a better option to solve the MOEED problems. Both the optimality of the solution to test systems and the convergence speed of the GWO algorithm are promising.

Keywords: *Grey wolf optimization, Economic dispatch, Environmental economic dispatch, nonconvex emission, Loss minimization.*

1. Introduction

The aim of Economic Load Dispatch (ELD) problem is, distribute the total power demand to each generating unit in the system in order to reduce the total fuel cost of the thermal unit to satisfy generator operating limit, power balance constraints. Now a day's coal fired power plants produce major electric power. These plants release pollutant emissions, these emissions quality based on calorific value of fuel and nature of coal used. To reduce the emission along with generation cost by modifying the ELD into Environmental Economic Dispatch (EED) problem, for this problem various algorithms are presented and discussed. In Ref. [1-4] Cuckoo Search, Firefly, Hopfield Modeling and Artificial Bee Colony algorithms are used to solve the classic ELD problem by including the transmission losses for various test systems.

Taguchi Self-Adaptive Real-Coded Genetic Algorithm (TSARGA) [5] has been developed to solve ELD problem with valve point loading. More recent algorithms, namely Harmony Search Algorithm (HSA) [6], Backtracking Search Algorithm (BSA) [7] and Modified Artificial Bee Colony Algorithm (MABCA) [8] are used to solve nonconvex ELD problem without transmission losses. Hybrid methods such as Sequential Quadratic Programming integrating with Cross-Entropy (CE-SQP) [9] and Chaotic Particle Swarm Optimization (CPSO-SQP) [10] are also employed to solve ELD problems.

Combined Environmental Economic Dispatch (CEED) problem is formulated by combining fuel cost with emission as a multi objective problem and is solved by cultural quantum-behaved PSO [11], modified ABC based on chaos theory [12]. By using the weighted sum method, the bi-objective problem is converted into CEED and it can be solved by normalization method [13]. By introducing price penalty factor also CEED problem formulated and it can be solved by Gravitational Search Algorithm (GSA) [14], hybrid optimization approach [15].

Some researchers develop Multi Objective EED (MOEED) problem. Backtracking Search Algorithm (BSA) [16], Differential Evolution (DE) algorithm [17] and quasi-oppositional teaching learning based optimizations [18] are developed to solve MOEED problem. A hybrid method called glow-worm swarm optimization algorithm with topsis [19] and hybrid ant optimizations [20] are proposed for resolving the controlled MOEED problem.

To solve the ELD and EED problems better and new algorithms have been recommended in the literature. These are Global Particle Swarm Optimization (GPSO) [21] and Flower Pollination Algorithms (FPA) [22]. These recently developed algorithms are used for finding the global optimal solution for practical generating system applications.

Recently, Seyedali Mirjalili and Saremi [23] proposed Grey Wolf Optimization (GWO), to find the better solution in the multiple functions. Grey wolf hunting behavior is used for finding optimal solutions in GWO. The GWO obtain as an optimizing tool in this paper based on solutions to the MOEED problem.

The remainder of the paper is sectionalized as follows. In section 2, mathematical model of MOEED problem is executed. In section 3, an objective function framed which requires to be optimized. The GWO is described in part 4. Test system simulation solutions are given in Section 5 for the MOEED. Section 6 focuses on the conclusions of the proposed work.

2. Mathematical Modeling of the MOEED Problem

Conventionally, the fuel cost and emissions are minimized by single objective function as MOEED problem, while satisfying the system constraints. This section describes the problem formulation.

2.1. Problem objectives

2.1.1. Fuel cost minimization:

The problem of ELD is non-linear because the generator fuel cost function is based on input-output characteristics of boiler, turbine and generator set. Mathematically, the ELD can be formulated as in Eqn. (1):

$$F_1 = F_C(P_G) = \sum_{k=1}^{N_G} (a_k P_{Gk}^2 + b_k P_{Gk} + c_k) \quad (\$/h) \qquad (1)$$

2.1.2. Fuel cost minimization with valve-point loading:

For thermal plants, the cost function is represented as a sinusoidal function, since it contains valve-point loading, given in Eqn. (2).

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$$F_2 = F_C(P_G) = \sum_{k=1}^{N_G} (a_k P_{Gk}^2 + b_k P_{Gk} + c_k) + \left| e_{ck} \times \sin(f_{ck} \times (P_{Gk}^{min} - P_{Gk})) \right| \quad (\$/h) \tag{2}$$

2.1.3. Minimization of emission objective:

The fossil fuel power plants produce pollutants such as NO_X, CO_2 and SO_2 emissions which are usually represented by separate quadratic functions. Nevertheless, by combining all the pollutants as single emission introducing exponential function to the quadratic emission function as given in Eqn. (3) for overall emission level of the pollutants.

$$F_3 = E(P_G) = \sum_{k=1}^{N_G} (\alpha_k P_{Gk}^2 + \beta_k P_{Gk} + \gamma_k) + \xi_{ck} \times \exp(P_{Gk} \lambda_k) \quad (ton/h) \tag{3}$$

2.1.4. Power loss minimization:

The total power generation of the system must satisfy the power requirement and power losses. This loss can be computed as follows using Eqn. (4):

$$F_4 = P_L(P_G) = \sum_{k=1}^{N_G} (P_{Gk} - P_D) \quad (MW) \tag{4}$$

2.2. Problem constraints

2.2.1. Inequality constraint:

Any generator active power output must satisfy the following constraint as follows:

$$P_{Gk}^{min} \le P_{Gk} \le P_{Gk}^{max} \tag{5}$$

2.2.2. Equality constraints:

The equality constraint for any power system can be represented as Eqn. (6):

$$\sum_{k=1}^{N_G} (P_{Gk} - P_D - P_L) = 0 \tag{6}$$

Where P_L is the active power loss in transmission lines, it can be represented as:

$$P_L = \sum_{j=1}^{N_G} \sum_{k=1}^{N_G} P_{Gj} B_{jk} P_{Gk} + \sum_{j=1}^{n} B_{0j} P_{Gj} + B_{00} \tag{7}$$

3. Formulation of overall MOEED Problem

The objective function $OF()$ must define for calculating the fitness of each individual in the search agents; the calculation is normalized between 0 and 1. The Eqn. (8) shows objective function $OF()$.

$$OF() = \text{minimize } (F_1, F_2 \ldots\ldots F_{N_{obj}}) \tag{8}$$

The better value of the above $OF()$ has to be found out subject to constraints given by Eqn. (5) and Eqn. (6). CEED problem can be formulated by any one of the following methods.

3.1. Weighted sum method:

The fuel cost and emission objective problem is converted into single objective CEED problem given by Eqn. (9) by assuming weighting factor proportion to the importance of the objective.

$$\text{Minimize } F = W \times F_2 + (1 - W) \times F_3 \tag{9}$$

3.2. Price penalty factor method:

Price penalty factor (h) in (\$/Kg) is computed by taking the ratio between the maximum value of fuel cost in (\$/h) to the maximum value of emission in (ton/Kg). The objective function with price penalty factor is given in Eqn. (10).

$$\text{Minimize } F = W \times F_2 + (1 - W) \times h \times F_3 \tag{10}$$

$$h = \frac{F_2(P_{Gk}^{max})}{F_3(P_{Gk}^{max})}, \quad k = 1, 2, 3 \ldots\ldots N_G \tag{11}$$

4. Grey Wolf Optimization and its Application to the MOEED Problem

4.1. Grey wolf optimization

Mirjalli introduced the Grey Wolf Optimization (GWO) algorithm [23], which is based on the hunting behaviour of the grey wolves in nature. They have social dominant hierarchy as alpha (α) beta (β), omega (ω), and delta (δ) types of grey wolves. The grey wolves have different groups for different activities like making a group for staying, hunting the prey.

4.1.1. Searching for prey

The search process is started with random initialization of candidate solutions (wolves) from the search space. Grey wolves separate from each other for searching the prey and gather after they find it.

4.1.2. Encircling prey

After searching a prey, grey wolves encircles that prey, encircling behavior can be mathematically represented by Eqn. (12) and Eqn. (13) given below.

$$\vec{E} = \left| \vec{O}.\vec{X}_p(k) - \vec{X}(k) \right| \tag{12}$$

$$\vec{X}(k+1) = \vec{X}_p(k) - \vec{B}.\vec{E} \tag{13}$$

Here current iteration is represented by k. $\vec{B}$ and $\vec{O}$ are the coefficient vectors. $\vec{B}$ is used for maintaining the distance between search agents grey wolves (GW) and prey. $\vec{O}$ represents obstacles in the hunting path of the prey. Here grey wolves position vector represented by $\vec{X}$ and position vector of the prey indicate by $\vec{X}_p$. The vectors $\vec{B}$ and $\vec{O}$ are computed as given in Eqn. (14) and Eqn. (15):

$$\vec{B} = 2 \times \vec{l} \times \vec{r}_1 - \vec{l} \tag{14}$$

$$\vec{O} = 2 \times \vec{r}_2 \tag{15}$$

4.1.3. Hunting

After encircling the prey, grey wolves concentrate on hunting. The hunting is generally guided by α, β and ω types of wolves. Among these, α provides the best candidate solution. Mathematically, hunting behaviour of grey wolves is formulated by (16)-(22).

$$E_\alpha = \left| \left(\vec{O}_1 * \vec{X}_\alpha(k) \right) - \vec{X}(k) \right| \tag{16}$$

$$E_\beta = \left| \left(\vec{O}_2 * \vec{X}_\beta(k) \right) - \vec{X}(k) \right| \tag{17}$$

$$E_\omega = \left| \left(\vec{O}_3 * \vec{X}_\omega(k) \right) - \vec{X}(k) \right| \tag{18}$$

$$\vec{X}_1 = \vec{X}_\alpha(k) - \left(\vec{B}_1 * \vec{E}_\alpha \right) \tag{19}$$

$$\vec{X}_2 = \vec{X}_\beta(k) - \left(\vec{B}_2 * \vec{E}_\beta \right) \tag{20}$$

$$\vec{X}_3 = \vec{X}_\omega(k) - \left(\vec{B}_3 * \vec{E}_\omega \right) \tag{21}$$

$$\vec{X}(k+1) = \frac{(\vec{X}_1 + \vec{X}_2 + \vec{X}_3)}{3} \tag{22}$$

4.1.4. Attacking prey

After completion of hunting, grey wolves attack the prey. Based on the location of α, β and ω category grey wolves, the GWO algorithm allows the search agents, i.e., Wolves to update their positions to attack the prey. In order to approaching to the prey, two parameters $\vec{a}$ and $\vec{A}$ are considered. Here, $\vec{a}$ linearly decreases from 2 to 0 as the iterations increases and fluctuations of $\vec{A}$ is also decreased with $\vec{a}$ .The flowchart of the GWO algorithm is depicted in Figure. 1.

4.2. Implementation of the GWO for the MOEED problem

The implementation steps of the GWO in the solution of the MOEED problem of this work are shown below.

Implementation steps of the GWO algorithm in MOEED problems

Step 1 Initialization

- (a) Read cost coefficients, emission coefficients and B coefficients.
- (b) Set power limits of each generator output.
- (c) Set number of search agents and maxiter.
- (d) Read GWO parameters: lower, upper limits of search space.

Step 2 Initialize the positions of the α, β and ω, initial fitness values randomly.

Alpha_pos=zeros(1,dim);
Alpha_score=inf;
Beta_pos=zeros(1,dim);
Beta_score=inf;
Omega_pos=zeros(1,dim);
Omega_score=inf;
Positions=rand(SearchAgents_no,dim).*(ub-lb)+lb;

Step 3 Set the time step t=0.

Step 4 Compute the initial positions of the objective function. Set the previous best position of each alpha to his current position.

Step 5 Let t=t+1.

Step 6 Select the neighbor of each alpha and compute the objective function for each alpha.

Step 7 Update the historical best position among the search agents and previous best position of each alpha.

Step 8 Repeat from Step 6 till the beat value obtained for objective function by setting convergence error (0.00001) rather than before reaching maximum iterations.

Step 9 Determine the best generation powers corresponding to get optimal value for the objective function.

5. Simulation Results

The proposed GWO algorithm has been applied on four different test systems for solving MOEED problem. Due to the random number generation in the optimization process, 30 runs are considered for optimizing each test system. For achieving the highest quality results, control parameter values are tuned in each system. Two methodologies are considered for solving MOEED problems as follows:

Methodology 1 –Minimizing generation cost, Emission and Loss separately.

Methodology 2–Minimizing the EED problem as a single objective function

5.1. 6-Unit System (IEEE 30-bus)

The IEEE 30-bus 6-Unit system is considered as test system 1. Data is taken from [21], with power demand of 283.4 MW. The maximum iteration and search agents are set to 500 and 50 respectively.

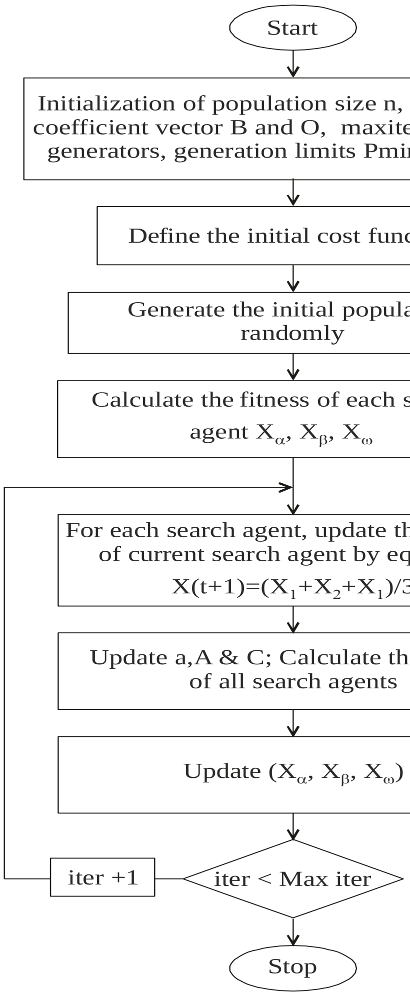

Fig.1. Flowchart of GWO

Table 1 shows the optimal solution for the test system with the 30 trails run. When generation cost, emission minimization as objective functions, GWO reaches the optimal values as 604.9680 ($/h), 0.194182 (ton/h). With the loss minimization as objective losses are reduced upto 0.6357 MW. For Methodology 2 the optimal value is 598.9678 ($/h) by considering the weighting factor as 0.6. The convergence curve for cost minimization and CEED minimizations are shown in Figure. 2.

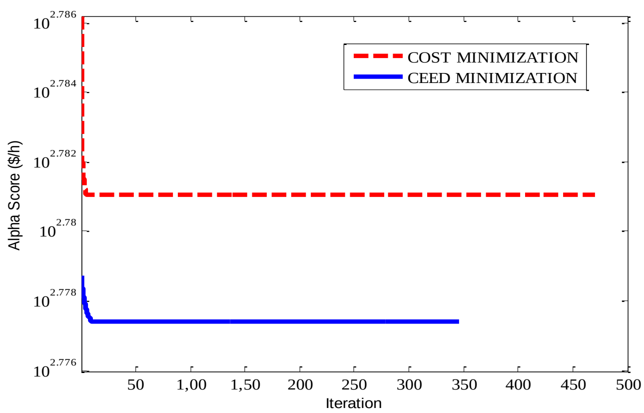

Fig.2. Convergence characteristics of GWO in 6-unit system with demand 283.4 MW

From the Figure 2, it can be concluded that during the cost minimization the optimal value is 604.9680 ($/h), and with CEED minimization optimal value is 598.9678 ($/h). From table

1, it can be observed that incase of CEED minimization fuel cost, emission and losses are reduced as compared with separately considering the fuel cost minimization.

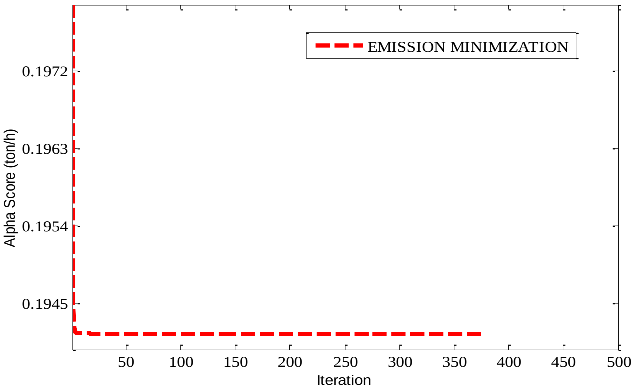

Fig.3. Emission minimization convergence characteristics of GWO in 6-unit system

Emission minimization, loss minimization convergence characteristics is shown in Figure 3 and Figure 4 for 6-unit system. From Figure 2, it can be concluded that emission minimization optimal value is 0.194182 (ton/h). From Figure 3, it can be concluded that loss minimization optimal value is 0.6357 (MW). From table 1, it can be observed that loss minimization having less fuel cost as compare with emission minimization, because 6-unit system having less losses.

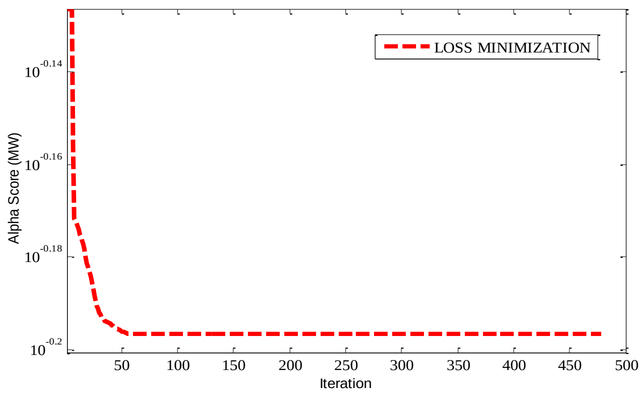

Fig.4. Loss minimization convergence characteristics of GWO in 6-unit system

5.2. 10-Unit System

The 10-Unit system with power demand of 2000 MW is considered as test system 2, data is taken from [21]. The maximum iteration and search agents are set to 1000 and 100 respectively. Table 2 shows the best solution for the test system among the 30 trail runs with transmission network loss. Table 5 shows the comparison results of the proposed method with other methods. When generation cost, emission minimization as objective functions, GWO reaches the optimal values as 111260.1684 ($/h), 3932.2458 (ton/h). In loss minimization the losses reduce upto 78.3545 MW. For Methodology 2 the optimal value is 111729.4238 ($/h) by considering the weighting factor as 0.6.

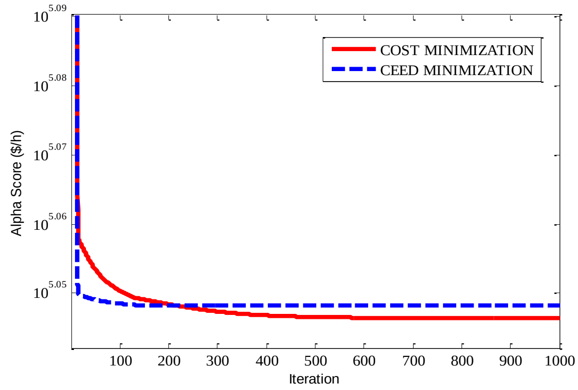

Fig.5. Convergence characteristics of GWO in 10-unit system with demand 2000 MW

From the Figure 5, it can be conclude that for cost minimization the optimal value is 111260.1684 ($/h), CEED minimization optimal value is 111729.4238 ($/h). From the table 2 observed that incase of CEED minimization, emission and losses are reduced as compare with separately considering the fuel cost minimization. But due to large emission for 10-unit system the fuel cost is high for CEED minimization.

Emission minimization, loss minimization convergence characteristics is shown in Figure 6 and Figure 7 for 10-unit system. From Figure 6, it can be seen that with emission minimization the optimal value is 3932.2458 (ton/h). From Figure 7, it can be concluded that for loss minimization the optimal value is 78.3545 (MW). From table 2 observed that fuel cost during loss minimization high as compared with emission minimization, because 10-unit system has considerable losses.

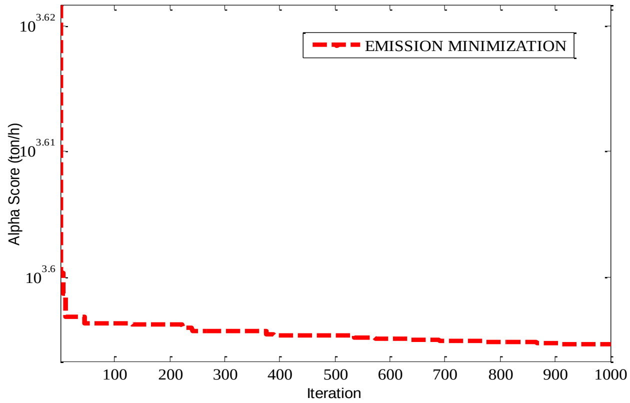

Fig.6. Emission minimization convergence characteristics of GWO in 10-unit system

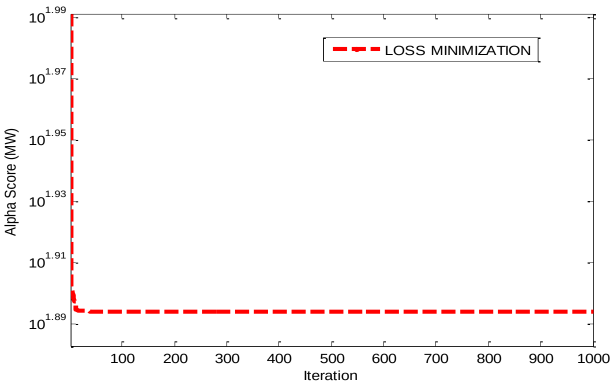

Fig.7. Loss minimization convergence characteristics of GWO in 10-unit system

Table 1: Best solution of the MOEED in Test System 1

Unit	Gen.Cost minimization	Emission minimization	Loss minimization	CEED minimization
P_1 (MW)	5.0000	40.9771	14.5479	50.0000
P_2 (MW)	30.0027	46.2680	22.6921	17.9027
P_3 (MW)	62.6633	54.2966	100.0000	15.0799
P_4 (MW)	102.8732	38.8768	120.0000	12.2135
P_5 (MW)	49.7734	54.3086	16.4488	15.0798
P_6 (MW)	34.9058	51.4360	10.0337	18.6104
P_{Total} (MW)	285.2260	286.6741	284.0357	284.6620
P_{loss} (MW)	1.8260	3.2741	0.6357	1.2620
Gcost ($/h)	604.9680	649.580393	627.708652	598.9678
E (ton/h)	0.225871	0.194182	0.263762	0.224180

Table 2: Best solution of the MOEED in Test System 2

Unit	Gen.cost minimization	Emission minimization	Loss minimization	CEED minimization
P_1 (MW)	54.9999	55.0000	54.9991	55.0000
P_2 (MW)	80.0000	80.0000	80.0000	80.0000
P_3 (MW)	107.1298	81.2864	120.0000	86.5185
P_4 (MW)	99.7753	81.4586	130.0000	84.2589
P_5 (MW)	82.1831	160.0000	160.0000	122.7405
P_6 (MW)	82.9540	240.0000	240.0000	137.9848
P_7 (MW)	300.0000	294.2273	300.0000	298.3461
P_8 (MW)	340.0000	297.0743	340.0000	314.6100
P_9 (MW)	470.0000	396.9401	372.6110	435.9407
P_{10} (MW)	470.0000	395.6071	280.7443	470.0000
P_T (MW)	2087.0422	2081.5937	2078.3544	2085.3992
P_l (MW)	87.0422	81.5937	78.3545	85.3992
G_{cost} ($/h)	111260.1684	116147.4002	117399.3058	111729.4238
E (ton/h)	4569.6282	3932.2458	4215.6740	4247.5237

5.3. 5.3. 11-Unit System

11-Unit system with power demand of 2500 MW is considered as test system 3; data is taken from [21]. Table 3 shows, the optimal values are 12274.4005 ($/h) and 1659.3385 (ton/h) respectively for fuel cost and emission objectives. For methodology 2 optimal value is 13388.8407 ($/h). The search agents are set to 150 and maximum iterations are 1000.

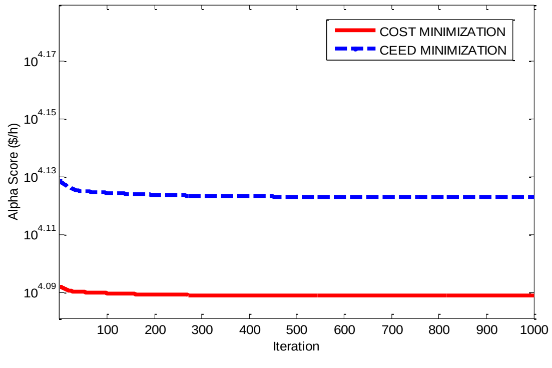

Fig.8. Convergence characteristics of GWO in 11-unit system with demand 2500 MW.

From the Figure 8, it can be concluded that with the cost minimization the optimal value is 12274.4005 ($/h), CEED minimization optimal value is 13388.8407 ($/h). From the table 3 observed that incase of CEED minimization, emission value, reduce as compared with separately considering the fuel cost minimization. But due to large emission for 11-unit system the fuel cost is high for CEED minimization.

Emission minimization convergence characteristics are shown in Figure 9 for 11-unit system. From Figure 9, it can be seen that with emission minimization the optimal value is 1659.3385 (ton/h). Loss coefficients are not available for a 11 - unit system, hence loss minimization is not performed.

Table 3: Best solution of the MOEED in Test System 3

Unit	Gen.Cost minimization	Emission minimization	CEED minimization
P_1 (MW)	57.1128	249.9997	118.1886
P_2 (MW)	40.4404	210.0000	99.2562
P_3 (MW)	57.8817	250.0000	137.2971
P_4 (MW)	277.7055	167.1760	197.9781
P_5 (MW)	186.8815	142.3523	156.5711
P_6 (MW)	249.1818	167.1649	194.5048
P_7 (MW)	177.0786	142.4271	155.5382
P_8 (MW)	380.1934	316.5953	343.3599
P_9 (MW)	341.6109	275.8269	301.4750
P_{10} (MW)	378.5829	302.6469	330.8309
P_{11} (MW)	353.3305	275.8109	465.0000
P_{Total} (MW)	2500	2500	2500
P_{loss} (MW)	0	0	0
Gcost ($/h)	**12274.4005**	13046.6590	**13388.8407**
Emission (ton/h)	2540.4167	**1659.3385**	2146.4602

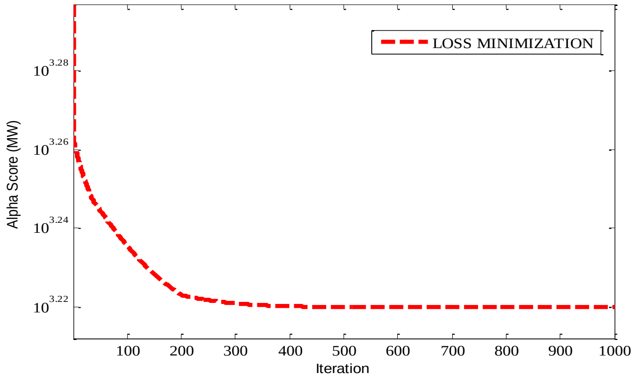

Fig.9. Emission minimization convergence characteristics of GWO in 11-unit system

5.4. 14-Unit System (IEEE 118-bus)

The IEEE 118-bus 14-Unit system with power demand of 950 MW is considered as test system 4, data is taken from [16]. The maximum iteration and search agents are set to 1000 and 200 respectively. Table 4 shows the best solution for the test system with 30 trails run with transmission network loss. When generation cost is objective function, GWO reaches the optimal value of 4297.3481 ($/h). In emission minimization, the optimal value is 23.4206 (ton/h). Similarly, for loss minimization the losses are reduced up to 8.2478 MW. For Methodology 2 the optimal value is 2666.1032 ($/h) by considering the weighting factor as 0.6. The convergence curve for cost minimization and CEED minimizations are shown in Figure 10.

From the Figure 10, it can be concluded that with the cost minimization the optimal value is 4297.3481 ($/h), CEED minimization optimal value is 2666.1032 ($/h). From the table 4 it can be observed that incase of CEED minimization fuel cost, emission and losses are reduced as compared with separately considering the fuel cost minimization.

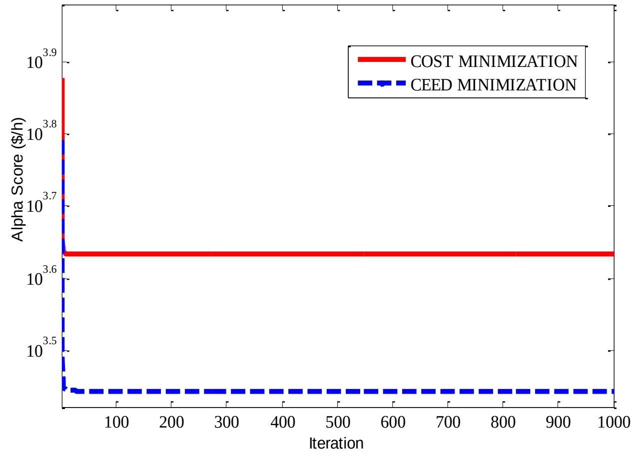

Fig.10. Convergence characteristics of GWO in 14-unit system with demand 950 MW

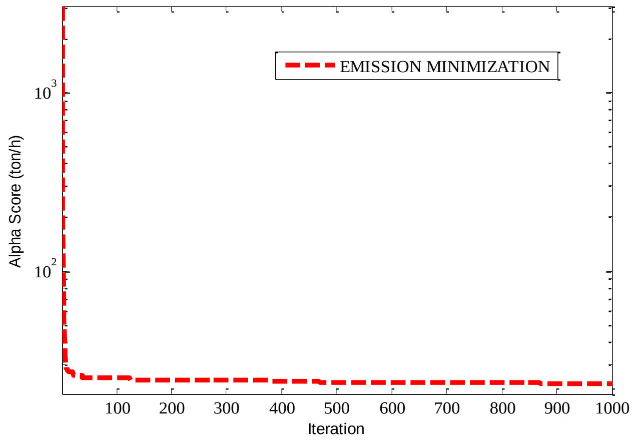

Fig.11. Emission minimization convergence characteristics of GWO in 14-unit system

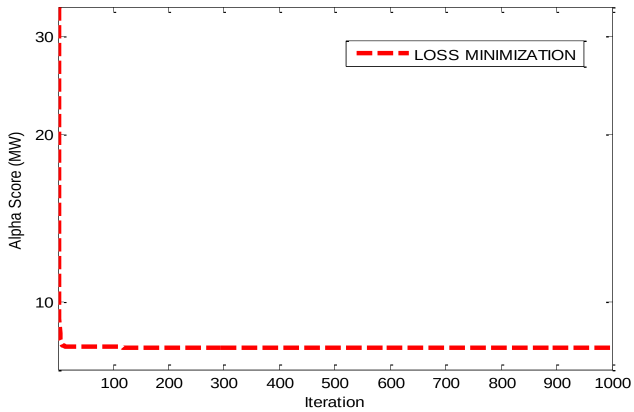

Fig.12. Loss minimization convergence characteristics of GWO in 14-unit system

Emission minimization, loss minimization characteristics is shown in Figure 11 and Figure 12 for 14-unit system. From Figure 11, it can be seen that with emission minimization the optimal value is 23.4206 (ton/h). From Figure 12, it can be concluded that with loss minimization the optimal value is 8.2478 (MW). From table 4 it can be observed that fuel cost with loss minimization less as compared with emission minimization, because considerable losses are present in 14-unit system.

Table 5 lists the results for the fuel cost minimization, emission minimization, loss minimization and CEED minimization for proposed method, the results are compared with BSA [16], GSA [14] and NGPSO [21] optimization approaches. From the results it can be concluded that GWO method is better as compared with other optimization approaches. The optimization approaches have considered cost minimization, emission minimization or combination of cost and emission minimization. But in this proposed method, loss minimization is also done. Here due to loss the minimization cost increased as compared with cost minimization but not as significantly as compared with emission minimization.

Table 4: Best solution of the MOEED in Test System 4

Unit	Gen.Cost minimization	Emission minimization	Loss minimization	CEED minimization
P_1 (MW)	104.7529	70.6158	50.0001	97.4398
P_2 (MW)	93.5369	50.0000	98.1021	62.8616
P_3 (MW)	50.0008	77.7359	51.7587	50.0041
P_4 (MW)	50.0029	88.4924	50.7316	69.3642
P_5 (MW)	50.0000	67.4347	101.0223	64.5712
P_6 (MW)	50.0046	50.0059	72.2261	50.0547
P_7 (MW)	50.0027	73.1876	56.9893	50.0601
P_8 (MW)	50.0000	72.0461	50.0830	50.0140
P_9 (MW)	65.9525	73.5259	50.0528	85.2185
P_{10} (MW)	50.0000	89.8744	111.9538	99.6985
P_{11} (MW)	65.3584	50.0000	67.9363	57.6080
P_{12} (MW)	180.8705	72.4940	94.6375	120.5579
P_{13} (MW)	50.0000	72.1882	50.1270	50.0901
P_{14} (MW)	50.0000	50.0646	50.1730	50.0095
P_{Total} (MW)	962.8295	959.9488	958.2478	959.8483
P_{Loss} (MW)	12.8295	9.9488	8.2478	9.8483
Gcost ($/h)	4297.3481	4540.9108	4423.2952	2666.1032
Emission (ton/h)	431.3851	23.4206	258.8645	137.9612

Table 5: Comparison result of four test systems

Problems	Methods	Min (F_2) ($/h)	Min (F_3) (ton/h)	Min (F_4) (MW)	Min (F) ($/h)
6-unit case [21] (P_d=283.4 MW)	BSA NGPSO GWO	605.9984 605.9983 604.9680	0.194179 0.194178 0.194182	NA NA 0.6357	615.5878 623.8636 598.9678
10-unit case [21] (P_d=2000 MW)	BSA GSA NGPSO GWO	111497.6409 11349.0000 111497.6308 111260.1684	3932.2432 4111.4 3932.2433 3932.2458	NA NA NA 78.3545	114859.9425 NA 116173.4808 111729.4238
11-unit case [21] (P_d=2500 MW)	GSA NGPSO GWO	12422.6626 12174.4005 12274.4005	2002.9499 1659.3383 1659.3385	NA NA NA	NA NA 13388.8407
14-unit case [16] (P_d=950 MW)	BSA GWO	4303.5861 4297.3481	25.2372 23.4206	NA 8.2478	4372.1966 2666.1032

6. Conclusion

In this paper, Grey Wolf Optimization algorithm has been proposed and implemented for solving multi objective environmental economic dispatch problem. The proposed GWO approach is implemented on four different test systems. It has been observed that only emission minimization is not economical, hence framed CEED objective function by using factors proportion to the importance of the objective. Power loss minimization also considered as the objective in this method. From the results it can be concluded that the proposed GWO algorithm provides better economical solutions than other methods reported in the literature. Moreover, the proposed GWO approach can also applied to dynamic ELD and multiple fuel ELD optimization problems.

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