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Economic Load Dispatch Using Grey Wolf Optimization

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ABSTRACT
This paper presents grey wolf optimization (GWO) to solve convex economic load dispatch (ELD) problem. Grey Wolf Optimization (GWO) is a new meta-heuristic inspired by grey wolves. The leadership hierarchy and hunting mechanism of the grey wolves is mimicked in GWO. The objective of ELD problem is to minimize the total generation cost while fulfilling the different constraints, when the required load of power system is being supplied. The proposed technique is implemented on two different test systems for solving the ELD with various load demands. To show the effectiveness of GWO to solve ELD problem results were compared with other existing techniques.
***Keywords**:* economic load dispacth;GWO; transmission loss

I. INTRODUCTION

Electrical power plays a pivotal role in the modern world to satisfy various needs. It is therefore very important that the electrical power generated is transmitted and distributed efficiently in order to satisfy the power requirement. Electrical power is generated in several ways. The economic scheduling of all generators in a system to meet desired demand is important problem in operation and planning of power system. The Economic Load Dispatch (ELD) problem is the most significant optimization problem in scheduling the generation of thermal generators in power system. In ELD problem, ultimate goal is to decrease the operation cost of the power generation system, while supplying the required power demanded. In addition to this, the various operational constraints of the system should also be satisfied. Traditional methods to solve ELD problem include the linear programming method, gradient method, lambda iteration method and Newton's method [1].

Dynamic programming is one of the techniques to solve ELD problem, but it suffer from problem of irritation of dimensionality [2]. Meta-heuristic techniques, such as genetic algorithms [3-5], differential evolution [6] , tabu search [7] ,simulated annealing [8], particle swarm optimization (PSO) [9], biogeography-based optimization [10],intelligent water drop algorithm[11] ,harmony search[12] ,gravitational search algorithm[13],firefly algorithm[14],hybrid gravitational search[15],cuckoo search (CS) [16],modified harmony search[17] have been successfully applied to ELD problems. Recently, a new meta-heuristic technique called grey wolf optimization has been proposed by Mirjalili et al., [18]. In this paper the ELD problem has been solved by using grey wolf optimization.

II. PROBLEM FORMULATION

The objective function of the ELD problem is to minimize the total generation cost while satisfying the different constraints, when the required load of power system is being supplied. The objective function to be minimized is given by the following equation:

$$F(P_g) = \sum_{i=1}^{n} (a_i P_{gi}^2 + b_i P_{gi} + c_i) \quad \ldots (1)$$

The overall fuel cost has to be reduced with the following constraints:

1) Power balance constraint

The total generation by all the generators must be equal to the total power demand and system's real power loss.

$$\sum_{i=1}^{n} P_{gi} - P_d - P_l \quad \ldots.. (2)$$

2) Generator limit constraint

The real power generation of each generator is to be controlled inside its particular upper and lower operating limits.

$$P_{gi}^{min} \le P_{gi} \le P_{gi}^{max} \quad i=1,2,...,ng \quad \ldots..(3)$$

Where

a_i, b_i, c_i : coefficient of fuel cost of i[th] generator, Rs/MW^2 h, Rs/MW h, Rs/h
$F(P_g)$: total fuel cost, Rs/h
n : number of generators
P_{gi}^{min} : Minimum limit of generation for i[th] generator, MW
P_{gi}^{max} : Maximum limit of generation for i[th] generator, MW
P_l : Transmission losses, MW
P_d : Power demand, MW

III. Grey Wolf Optimization (GWO)

The GWO is firstly proposed by Mirjalili et al., [18]. The algorithm was inspired by the democratic behavior and the hunting mechanism of grey wolves in the wild. In a pack, the grey wolves follow very firm social leadership hierarchy. The leaders of the pack are a male and female, are called alpha (α). The second level of grey wolves, which are subordinate wolves that help the leaders, are called beta (β). Deltas (δ) are the third level of grey wolves which has to submit to alphas and betas, but dominate the omega. The lowest rank of the grey wolf is omega (ω), which have to surrender to all the other governing wolves. The GWO algorithm is provided in the mathematical models as follows:

1) Social hierarchy

In the mathematical model of the social hierarchy of the grey wolves, alpha (α) is considered as the fittest solution. Accordingly, the second best solution is named beta (β) and third best solution is named delta (δ) respectively. The candidate solutions which are left over are taken as omega (ω). In the GWO, the optimization (hunting) is guided by alpha, beta, and delta. The omega wolves have to follow these wolves.

2) Encircling prey

The grey wolves encircle prey during the hunt. The encircling behavior can be mathematically modeled as follows [18]:

$$\vec{D} = \left|\vec{C}.\vec{X}_p(t) - \vec{X}(t)\right| \quad \ldots (4)$$

$$\vec{X}(t+1) = \vec{X}_p(t) - \vec{A}.\vec{D} \quad \ldots (5)$$

Where $\vec{A}$ and $\vec{C}$ are coefficient vectors, $\vec{X}_p$ is the prey's position vector, $\vec{X}$ denotes the grey wolf's position vector and 't' is the current iteration.

The calculation of vectors $\vec{A}$ and $\vec{C}$ is done as follows [18]:

$$\vec{A} = 2.\vec{a}.\vec{r}_1.\vec{a} \quad \ldots (6)$$

$$\vec{C} = 2.\vec{r}_2 \quad \ldots (7)$$

Where values of '$\vec{a}$ 'are linearly reduced from 2 to 0 during the course of iterations and r1, r2 are arbitrary vectors in gap [0, 1].

3) Hunting

The hunt is usually guided by the alpha, beta and delta, which have better knowledge about the potential location of prey. The other search agents must update their positions according to best search agent's position. The update of their agent position can be formulated as follows [18]:

$$\begin{Bmatrix} \vec{D}_\alpha = \left|\vec{C}_1.\vec{X}_\alpha - \vec{X}\right| \\ \vec{D}_\beta = \left|\vec{C}_2.\vec{X}_\beta - \vec{X}\right| \\ \vec{D}_\delta = \left|\vec{C}_3.\vec{X}_\delta - \vec{X}\right| \end{Bmatrix} \quad \ldots (8)$$

$$\begin{Bmatrix} \vec{X}_1 = \vec{X}_\alpha - \vec{A}_1.(\vec{D}_\alpha) \\ \vec{X}_2 = \vec{X}_\beta - \vec{A}_2.(\vec{D}_\beta) \\ \vec{X}_3 = \vec{X}_\delta - \vec{A}_3.(\vec{D}_\delta) \end{Bmatrix} \quad \ldots (9)$$

$$\vec{X}(t+1) = \frac{\vec{X}_1 + \vec{X}_2 + \vec{X}_3}{3} \quad \ldots (10)$$

4) Search for prey and attacking prey

The 'A' is an arbitrary value in the gap [-2a, 2a]. When |A| < 1, the wolves are forced to attack the prey. Attacking the prey is the exploitation ability and searching for prey is the exploration ability. The random values of 'A' are utilized to force the search agent to move away from the prey. When |A| > 1, the grey wolves are enforced to diverge from the prey.

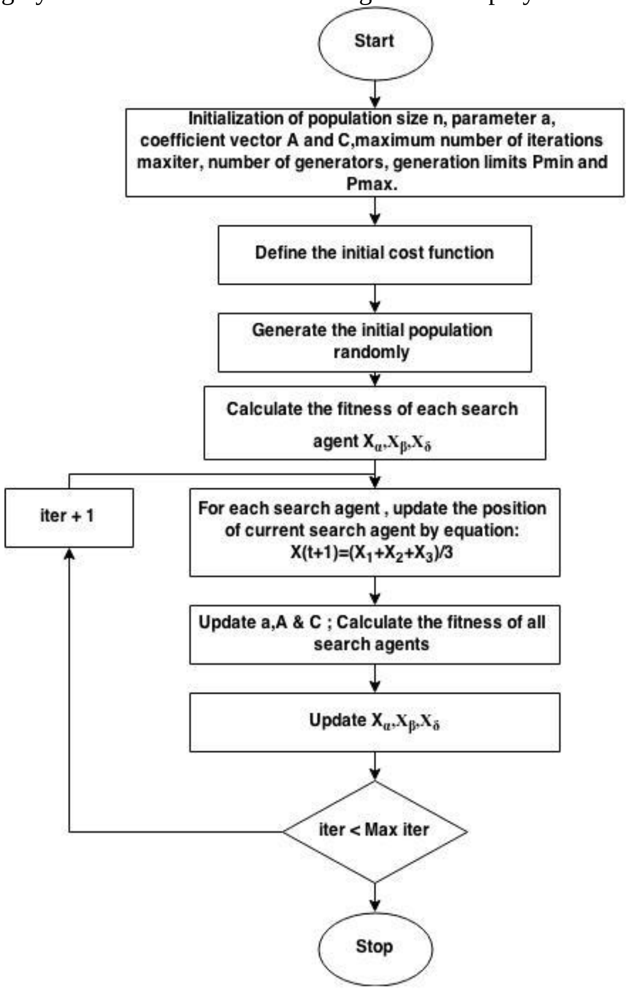

Fig 3.1: flowchart of GWO

IV. RESULTS & DISCUSSIONS

GWO has been used to solve the ELD problems in two diverse test cases for exploring its optimization potential, where the objective function was limited within power ranges of the generating units and transmission losses were also taken into account. The iterations performed for each test case are 500 and number of search agents (population) taken in both test cases is 30.

1) Test system I: Three generating units

The input data for three generators and loss coefficient matrix B_{mn} is derived from reference [16] and is given in table 4.1.The economic load dispatch for 3 generators is solved with GWO and results are compared with lambda iteration and cuckoo search.

Table 4.1: Generating unit data for test case I

Unit	a_i	b_i	c_i	P_{gi}^{min}	P_{gi}^{max}
1	0.03546	38.30553	1243.5311	35	210
2	0.02111	36.32782	1658.5696	130	325
3	0.01799	38.27041	1356.6592	125	315

$$B_{mn}=\begin{bmatrix} 0.000071 & 0.000030 & 0.000025 \\ 0.000030 & 0.000069 & 0.000032 \\ 0.000025 & 0.000032 & 0.000080 \end{bmatrix}$$

Table 4.2: GWO results for 3-unit system

Sr.no.	Techniques	Power demand (MW)	P_1(MW)	P_2(MW)	P_3(MW)	P_{Loss} (MW)	Fuel Cost (Rs/hr)
1	CS[16]	350	70.3012	156.267	129.208	5.77698	18564.5
	GWO		70.30259	156.289	129.184	5.77696	18564.483
2	CS[16]	450	93.9374	193.814	171.862	9.6127	23112.4
	GWO		93.9362	193.8043	171.872	9.6127	23112.363
3	CS[16]	500	105.88	212.728	193.306	11.9144	25465.5
	GWO		105.8848	212.7137	193.3157	11.91434	25465.469

Table 4.3: Comparison results of GWO for 3-Unit system

Sr.no.	Power demand (MW)	Fuel Cost (Rs/hr)		
		Lambda Iteration Method [16]	Cuckoo Search Algorithm [16]	Grey Wolf Optimization
1	350	18570.7	18564.5	18564.483
2	450	23146.8	23112.4	23112.363
3	500	25495.2	25465.5	25465.469

2) Test system II: Six generating units

The input data for six generators and loss coefficient matrix B_{mn} is derived from reference [16] and is given in table 4.4.The economic load dispatch for 6 generators is solved with GWO and results are compared with conventional quadratic programming, lambda iteration, particle swarm optimization and cuckoo search.

Table 4.4: Generating unit data for test case II

Unit	a_i	b_i	c_i	P_{gi}^{min}	P_{gi}^{max}
1	0.15240	38.53973	756.79886	10	125
2	0.10587	46.15916	451.32513	10	150
3	0.02803	40.39655	1049.9977	35	225
4	0.03546	38.30553	1243.5311	35	210
5	0.02111	36.32782	1658.5596	130	325
6	0.01799	38.27041	1356.6592	125	315

$$B_{mn}=\begin{bmatrix} 0.000014 & 0.000017 & 0.000015 & 0.000019 & 0.000026 & 0.000022 \\ 0.000017 & 0.000060 & 0.000013 & 0.000016 & 0.000015 & 0.000020 \\ 0.000015 & 0.000013 & 0.000065 & 0.000017 & 0.000024 & 0.000019 \\ 0.000019 & 0.000016 & 0.000017 & 0.000072 & 0.000030 & 0.000025 \\ 0.000026 & 0.000015 & 0.000024 & 0.000030 & 0.000069 & 0.000032 \\ 0.000022 & 0.000020 & 0.000019 & 0.000025 & 0.000032 & 0.000085 \end{bmatrix}$$

Table 4.5: GWO results for 6-unit system

Sr.no.	**Techniques**	**Power Demand (MW)**	**P_1 (MW)**	**P_2 (MW)**	**P_3 (MW)**	**P_4 (MW)**	**P_5 (MW)**	**P_6 (MW)**	**P_{Loss} (MW)**	**Fuel Cost (Rs/hr)**
1	Conventional[9]	600	23.90	10.00	95.63	100.70	202.82	182.02	15.07	32096.58
	CS[16]		23.8603	10	95.6389	100.708	202.832	181.198	14.2374	32094.7
	GWO		23.911	10	95.571	100.740	202.752	181.261	14.2373	32094.67
2	Conventional[9]	700	28.33	10.00	118.95	118.67	230.75	212.80	19.50	36914.01
	CS[16]		28.2908	10.00	118.958	118.675	230.763	212.745	19.4319	36912.2
	GWO		28.3514	10.00	118.887	118.748	230.704	212.737	19.4308	36912.14
3	Conventional[9]	800	32.63	14.48	141.54	136.04	257.65	243.00	25.34	41898.45
	CS[16]		32.5861	14.4843	141.548	136.045	257.664	243.009	25.3309	41896.7
	GWO		32.5408	14.8660	141.5021	136.0254	257.518	242.8632	25.3165	41896.63

Table 4.6: Comparison results of GWO for 6-Unit system

Sr.no.	**Power demand (MW)**	**Fuel Cost (Rs/hr)**				
		Lambda Iteration Method[16]	**Conventional Method[9]**	**PSO[9]**	**Cuckoo Search Algorithm[16]**	**Grey Wolf Optimization**
1	600	32129.8	32096.58	32094.69	32094.7	32094.67
2	700	36946.4	36914.01	36912.16	36912.2	36912.145
3	800	41959.0	41898.45	41896.66	41896.9	41896.632

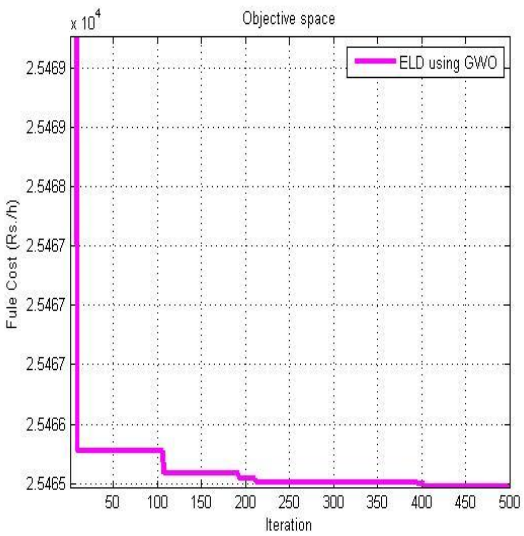

Fig 4.1: Convergence characteristics of test system I with 500MW demand

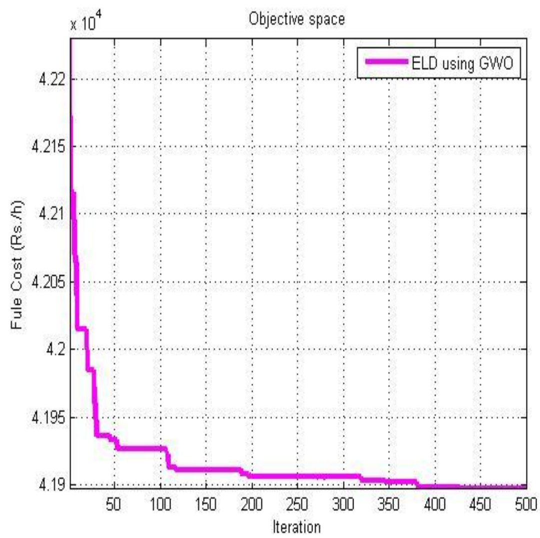

Fig 4.2: Convergence characteristics of test system II with 800MW demand

V. CONCLUSION

In this paper economic load dispatch problem has been solved by using GWO. The results of GWO are compared for three and six generating unit systems with other techniques. The algorithm is programmed in MATLAB(R2009b) software package. The results show effectiveness of GWO for solving the economic load dispatch problem. The advantage of GWO algorithm is its simplicity, reliability and efficiency for practical applications.

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