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Solving Economic Load Dispatch Problem using Grey Wolf Optimizer Method

Krunalkumar J. Gandhi, Nitin J. Patil

Abstract: ***The aim of economic load dispatch (ELD) is to accomplish the load demand with less fuel cost by the generators. This research shows a new grey wolf-inspired algorithm called the Grey Wolf Optimizer (GWO) to achieve ELD. The GWO algorithm follows mainly the grey wolves hierarchy and hunting scheme. The controlling hierarchy is driven by four wolves, namely alpha, beta, delta, and omega.***

Three critical phases of hunting are implemented, looking for a target, surrounding a target, and attacking a target. Now, on 20 generating units, the algorithm is used and is equated with Particle Swarm Optimization (PSO). The findings show that, compared to PSO, the GWO algorithm is set to yield economic results.

Keywords: ***Grey Wolf Optimizer, Particle Swarm Optimization, Economic Load Dispatch, leadership.***

I. INTRODUCTION

There are problems with optimization in many areas of science and technology. These issues can be very challenging owing to the real and practical quality of the objective function or limitations of a model. There are critical optimization issues with ED in power system operation and scheduling. By preparing generators to decrease the cost of the entire operating and to meet the load demand while meeting many similarities and inequity constraints. The ED primarily considers the generating capacity limitations plus the lack of load balance. In practical EDs, find prohibited operating zones (POZ), valve point effects, and ramp rate limitations with a multi-fuel option, necessarily providing the widest for the ED problem formulation [1]. Over the years, the classical mathematical programming method developed various strategies to explain ED [2–8]. However, they are susceptible to initial points and usually meet to a nearby optimal solution or differ entirely. Therefore, the traditional method did not describe the problem. Also, the conventional method typically has an underlying mathematical model and high speed of search. Hence, PSO to solve the ED problem using meta-heuristic optimization techniques has increased over the years [9]. Due to its simple, flexible and non-derivative mechanism, and indigenous evasion, meta-heuristic has become unusually frequent. [10].

First, they inspired by fundamental thoughts about real events and the behaviors of animals. Second, the approach to meta-heuristics suitability on various problems without any particular change in the optimization algorithm pattern. Third, there are significant sections of meta-heuristics with non-derivative systems. Meta-heuristics enhance issues stochastically than gradient-based optimization.

Finally, there is a better ability than traditional optimization techniques to prevent local optimization. It avoids inactivity in local alternatives because of the meta-heuristic's stochastic nature and searches the entire search area extensively. Hence, to clarify the problems with the ED, GWO is being introduced, proposed by Mirzalili [10].

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***** Correspondence Author

Krunalkumar J. Gandhi*, Electrical Engineering Department, D.N.Patel College of Engineering, Shahada, India. Email: krunal14586@yahoo.com

Nitin J. Patil, Instrumentation Engineering Department, D.N.Patel College of Engineering, Shahada, India. Email: nitinpatil2002@gmail.com

II. ECONOMIC DISPATCH ISSUES

The purpose of the economic dispatch is to decrease fuel expenses even though meeting certain parity and disparity limitations. The issue lies below.

A. Formulation of Economic Load Dispatch

The prime anxiety of the ED issue is to lower its objective function.

$$\min(F_T) = \min \sum_{i=1}^{N} F_i(P_{Gi}) \quad (1)$$

Where,

Ft - The total cost of fuel,

N - Number of units for generation

Fi (PGi) - the price of fuel for unit i produced.

B. Fuel Cost Minimization

Quadratic functions give the generator cost curve, so the total cost of fuel F(PG) in (RM / h) may be as follows:

$$F(P_{Gi}) = \sum_{i=1}^{N} a_i + b_i P_{Gi} + c_i P_{Gi}^2 \quad (2)$$

Where,

N - Generating units;

ai, bi, ci - the coefficients of cost for the i^{th} generator,

PG - The generator's actual power output vector and as follows:

$$P_G = [P_{G1}, P_{G2}, \dots, P_{GN}] \quad (3)$$

C. Limitations

• Power Stability/Equality Limitation

The total power generated should cover the total power demand PD and the transmission loss, P_{loss} can be defined by the following:

$$\sum_{i=1}^{N} P_{Gi} - P_D - P_{loss} = 0 \quad (4)$$

For precise economic dispatch, the transmission loss is delivered through the B-matrix technique.

$$P_{loss} = \sum_{i=1}^{N}\sum_{j=1}^{N} P_i B_{ij} P_j + \sum_{i=1}^{N} B_{i0} P_i + B_{00} \quad (5)$$

Where,

Pj = generation of unit j (MW).

Bij = ijth segment of the square matrix loss coefficient.

Bi0 = ith loss coefficient component.

B00 = constant of loss coefficient.

• Capacity/Inequality Limit of generation

The generator's lower and higher parameters control the actual power output of each generator for steady operation:

$$P_{Gi}^{min} \le P_{Gi} \le P_{Gi}^{max} \qquad i = 1,2,\ldots,N \quad (6)$$

III. GREY WOLF OPTIMIZER

The motivation for the suggested technique is conferred previously. A mathematical model is then given.

A. Inspiration

Grey wolves are resolute to be hunters, so they are on top of the hierarchy. On average, they live in groups of around 5–12. In particular, as presented in Figure 1, they have an extremely rigid social control.

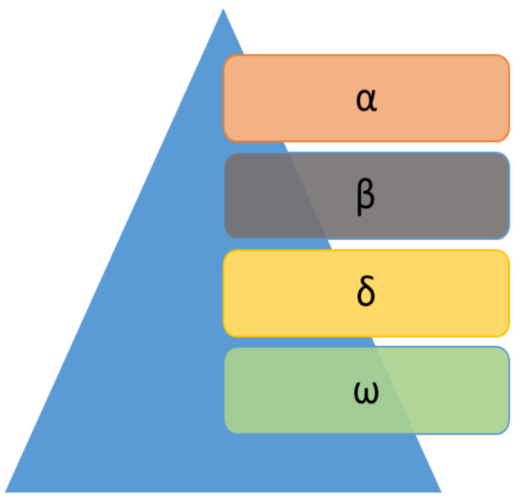

Fig. 1. Grey wolf social hierarchy

The leader, known as Alpha, may be male or female. The choices of Alpha are laid in the box. However, some kinds of self-governing behavior have also been studied, meaning that in the box leadership era, Alpha is not always the most powerful, but the most efficient. Specify that the box's discipline is essential rather than strength. Beta is the Grey Wolf hierarchy's second level. If any of the Alpha Wolves die or become too old, he or she is likely to be the best candidate. Beta Wolf considers as an essential part of alpha and a disciplinarian of the box. The beta emphasizes the commands of Alpha in the box and suggests a response to first level Alpha wolves. The third level is the Delta. Delta wolves are going through alpha and beta, but they are controlling the omega. This type contains guides, guards, leaders, stalkers, and carers. Lookout the area's limits and warn the box if any danger is Scouts' responsibilities. It is the responsibility of Sentries to ensure the box's safety and security. The elderly wolves of experience are alpha or beta. Hunters aid in hunting targets for the alpha and beta and supplying food for the box. Finally, caretakers' responsibilities are to look after the weak, sick, and offended wolves in the box. The grey wolf's smallest state is omega. It regarded as a substitute part. These are the wolves that can lastly consume. Omega may not seem to be an essential figure in the box, but it does support keeping the complete box's dominance structure. Omega also sometimes has midwives inside the box. Another noteworthy social characteristic of grey wolves is crowd hunting. The essential phases of grey wolf hunting, according to Muro et al.[11], are:

- Locating, chasing, and reaching goals.
- Following, adjoining, and annoying the goal until it stops the movement.
- Assault on goal

To framework GWO, hunting techniques, and grey wolves' social hierarchy is demonstrated mathematically.

IV. MATHEMATICAL MODEL AND ALGORITHM

This chapter gives accurate depictions of the objectives of the social hierarchy, monitoring, surrounding, and attacking.

A. Social Hierarchy

In the form of Alpha (α), a suitable solution is obtained. Beta (β) is therefore second, and delta (δ) is the third-best. For the remainder applicants, Omega (ω) is regarded as the answer. In the GWO algorithm, α, β, and δ dictate optimization. These three wolves are followed by ω wolves.

B. Surrounding Target

Wolves surround their aim when they do hunting. The surrounding action is described by the following equations [5]:

$$\vec{D} = \left|\vec{C}.\vec{Xp}(t) - \vec{X}(t)\right| \quad (7)$$

$$\vec{X}(t+1) = \vec{Xp}(t) - \vec{A} * \vec{D} \quad (8)$$

Where

t - Iteration of current,

$\vec{A}$,$\vec{C}$ - Coefficient vectors,

$\vec{Xp}$ - Target's position vector,

$\vec{X}$ - Grey wolf's position vector.

The following expression calculates the vector $\vec{A}$ and the vector $\vec{C}$:

$$\vec{A} = 2\vec{a}.\vec{r_1} - \vec{a} \quad (9)$$

$$\vec{C} = 2.\vec{r_2} \quad (10)$$

Where part of $\vec{a}$ is reduced linearly from 2 to 0 as iterations evolution and, r_1 and r_2 are random vectors, lies in [0, 1].

The search field location of alpha, beta, and delta are used to determine the final situation X (t+1). These situations are articulated using the following phrases:

$$\vec{D_\alpha} = |\vec{C_1}\vec{X_\alpha} - \vec{X}|, \vec{D_\beta} = |\vec{C_2}\vec{X_\beta} - \vec{X}|, \vec{D_\delta} = |\vec{C_3}\vec{X_\delta} - \vec{X}| \quad (11)$$

$$\vec{X_1} = \vec{X_\alpha} - \vec{A_1}(\vec{D_\alpha}), \vec{X_2} = \vec{X_\beta} - \vec{A_2}(\vec{D_\beta}), \vec{X_3} = \vec{X_\delta} - \vec{A_3}(\vec{D_\delta}) \quad (12)$$

$$\vec{X}(t+1) = \frac{\vec{X_1}+\vec{X_2}+\vec{X_3}}{3} \quad (13)$$

GWO optimization begins with producing random grey wolves' population that can be called a solution for applicants. Alpha, beta, and delta wolves imagine the likely place of the goal during the simulation. The adaptive values of a and A are guarantees to search and to use data. Candidate solutions move away from the goal if $\vec{A} > 1$ and converge if $\vec{A} < 1$. Finally, the initially defined criterion concludes the GWO algorithm.

GWO algorithm for economic load dispatch is summarized and displayed in figure 2.

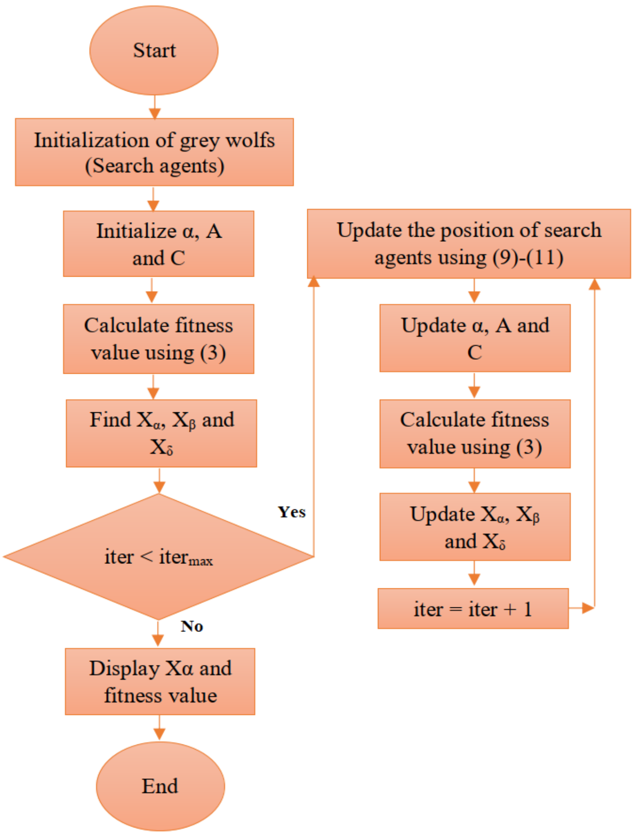

Fig. 2. Flowchart of the system

V. SIMULATION RESULTS

A 20 generators system used to display GWO's efficiency. The data of the used system is in Table I [12], [13]. Only transmission loss is taken into account, and it does not consider the valve point loading effect. This system has a 2500 MW load demand. The results of GWO are compared with the results of PSO, and the GWO can provide an optimization algorithm for this implementation.

The loss coefficients summarized in Table III. GWO and PSO simulation results are provided in Table II, where actual power generation is achieved by individual generators for a specified demand and total cost. As of Table III, the GWO-based system's lowest possible cost for the test scheme is 62457 $/h. Besides, the produced power by the GWO is in each generator's minimum and maximum limits. Therefore, GWO's output was determined to be the best compared to PSO.

Table-I - 20 generators system data

Unit	P_{Gi}^{min} (MW)	P_{Gi}^{max} (MW)	α ($/MW)	B ($/MW)	c ($/MW)
1	150	600	0.00068	18.19	1000
2	50	200	0.00071	19.26	970
3	50	200	0.0065	19.8	600
4	50	200	0.005	19.1	700
5	50	160	0.00738	18.1	420
6	20	100	0.00612	19.26	360
7	25	125	0.0079	17.14	490
8	50	150	0.00813	18.92	660
9	50	200	0.00522	18.27	765
10	30	150	0.00573	18.92	770
11	100	300	0.0048	16.69	800
12	150	500	0.0031	16.76	970
13	40	160	0.0085	17.36	900
14	20	130	0.00511	18.7	700
15	25	185	0.00398	18.7	450
16	20	80	0.0712	14.26	370
17	30	85	0.0089	19.14	480
18	30	120	0.00713	18.92	680
19	40	120	0.00622	18.47	700
20	30	100	0.00773	19.79	850

VI. CONCLUSION

This article implemented the GWO technique to the economic issue. The achieved results confirm that GWO has been efficiently applied to address multiple Dispatch issues. GWO can produce very economical outcomes by decreasing total fuel cost and minimizing transmission losses. GWO can convert an enhanced solution close to optimum performance and retains better merging characteristics compared to PSO. Also, GWO exhibits reasonable stability among search and use, leading to elevated optima local avoidance.

Overall, it is concluded, from the simulation and tabular observations that, the goal of ELD is efficiently determined by application of GWO.

Table II - Total power generation and total cost of different metaheuristic methods

Unit	GWO	PSO
P1	512.3369	526.1092
P2	168.5350	169.1183
P3	126.6437	126.8066
P4	102.5921	102.8665
P5	113.6945	113.6946
P6	73.6496	73.5857
P7	115.2911	115.2936
P8	116.2030	116.3974
P9	100.6242	100.4232
P10	106.5265	106.0275
P11	150.1631	150.2405
P12	292.7661	292.7772
P13	119.1202	119.1221
P14	31.6176	30.8522
P15	116.0046	115.8180
P16	36.2951	36.2198
P17	66.6933	66.8654
P18	88.0136	87.9774
P19	100.8275	100.8076
P20	54.4073	54.3174
Total power output (MW)	2592.01	2605.32
Total transmission loss (mw)	92.0050	105.32
Total generation cost($/h)	62457	62594

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Table III- Loss coefficients for 20 generators system

8.7	0.43	-4.61	0.36	0.32	-0.66	0.96	-1.6	0.8	-0.1	3.6	0.64	0.79	2.1	1.7	0.8	-3.2	0.7	0.48	-0.7
0.43	8.3	-0.97	0.22	0.75	-0.28	5.04	1.7	0.54	7.2	-0.28	0.98	-0.46	1.3	0.8	-0.2	0.52	-1.7	0.8	0.2
-4.61	-0.97	9	-2	0.63	3	1.7	-4.3	3.1	-2	0.7	-0.77	0.93	4.6	-0.3	4.3	0.38	0.7	-2	3.6
0.36	0.22	-2	5.3	0.47	2.62	-1.96	2.1	0.67	1.8	-0.45	0.92	2.4	7.6	-0.2	0.7	-1	0.86	1.6	0.87
0.32	0.75	0.63	0.47	8.6	-0.8	0.37	0.72	-0.9	0.69	1.8	4.3	-2.8	-0.7	2.3	3.6	0.8	0.2	-3	0.5
-0.66	-0.28	3	2.62	-0.8	11.8	-4.9	0.3	3	-3	0.4	0.78	6.4	2.6	-0.2	2.1	-0.4	2.3	1.6	-2.1
0.96	5.04	1.7	-1.96	0.37	-4.9	8.24	-0.9	5.9	-0.6	8.5	-0.83	7.2	4.8	-0.9	-0.1	1.3	0.76	1.9	1.3
-1.6	1.7	-4.3	2.1	0.72	0.3	-0.9	1.2	-0.96	0.56	1.6	0.8	-0.4	0.23	0.75	-0.56	0.8	-0.3	5.3	0.8
0.8	0.54	3.1	0.67	-0.9	3	5.9	-0.96	0.93	-0.3	6.5	2.3	2.6	0.58	-0.1	0.23	-0.3	1.5	0.74	0.7
-0.1	7.2	-2	1.8	0.69	-3	-0.6	0.56	-0.3	0.99	-6.6	3.9	2.3	-0.3	2.8	-0.8	0.38	1.9	0.47	-0.26
3.6	-0.28	0.7	-0.45	1.8	0.4	8.5	1.6	6.5	-6.6	10.7	5.3	-0.6	0.7	1.9	-2.6	0.93	-0.6	3.8	-1.5
0.64	0.98	-0.77	0.92	4.3	0.78	-0.83	0.8	2.3	3.9	5.3	8	0.9	2.1	-0.7	5.7	5.4	1.5	0.7	0.1
0.79	-0.46	0.93	2.4	-2.8	6.4	7.2	-0.4	2.6	2.3	-0.6	0.9	11	0.87	-1	3.6	0.46	-0.9	0.6	1.5
2.1	1.3	4.6	7.6	-0.7	2.6	4.8	0.23	0.58	-0.3	0.7	2.1	0.87	3.8	0.5	-0.7	1.9	2.3	-0.97	0.9
1.7	0.8	-0.3	-0.2	2.3	-0.2	-0.9	0.75	-0.1	2.8	1.9	-0.7	-1	0.5	11	1.9	-0.8	2.6	2.3	-0.1
0.8	-0.2	4.3	0.7	3.6	2.1	-0.1	-0.56	0.23	-0.8	-2.6	5.7	3.6	-0.7	1.9	10.8	2.5	-1.8	0.9	-2.6
-3.2	0.52	0.38	-1	0.8	-0.4	1.3	0.8	-0.3	0.38	0.93	5.4	0.46	1.9	-0.8	2.5	8.7	4.2	-0.3	0.68
0.7	-1.7	0.7	0.86	0.2	2.3	0.76	-0.3	1.5	1.9	-0.6	1.5	-0.9	2.3	2.6	-1.8	4.2	2.2	0.16	-0.3
0.48	0.8	-2	1.6	-3	1.6	1.9	5.3	0.74	0.47	3.8	0.7	0.6	-0.97	2.3	0.9	-0.3	0.16	7.6	0.69
-0.7	0.2	3.6	0.87	0.5	-2.1	1.3	0.8	0.7	-0.26	-1.5	0.1	1.5	0.9	-0.1	-2.6	0.68	-0.3	0.69	7

AUTHORS PROFILE

Krunalkumar J. Gandhi is working as an Assistant Professor in the Electrical Engineering department at D. N. Patel College of Engineering, Shahada. He has completed M.Tech from Rajasthan Technical University, Kota, India, in 2016, and received a degree of B.E. from North Maharashtra University, Jalgaon, in 2010. He is highly interested in the area of power system design, optimization, and control.

Nitin J. Patil is working as Professor in the Instrumentation Engineering department at D. N. Patel College of Engineering Shahada. He has received his Ph.D. Degree and M.E. from SRTMU, Nanded, India in 2013, and 2000 respectively. He cleared B.E. from North Maharashtra University, Jalgaon, in 1997. He is highly interested in areas like fuzzy control, fractional control, nonlinear control, optimization, and adaptive control.