Implementations of Golden Jackal Algorithm for Solving CCFELD Problems

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Abstract

This study offers the Golden Jackal Optimization (GJO) algorithm, an effective and trustworthy swarm optimization for tackling economic load dispatch (ELD) issues using cubic fuel cost functions. The presence of equal and unequal constraints of the non-smooth cost functions of a practical ELD has caused difficulties in finding an overall optimal result. The suggested GJO is tested first with quadratic cost functions as well as the cubic fuel cost functions to demonstrate its usefulness and efficiency. Three generator systems, five generator systems, six generating systems, 26 generators with quadratic and cubic fuel cost functions have all been used to assess the proposed GJO algorithm. Numerous case studies and evaluation with the other existing algorithms have substantiated that the suggested GJO technique yields outstanding outcomes.

Keywords: Economic Load Dispatch (ELD), Golden Jackal Optimization (GJO), Cubic Cost Fuel Function (CCF) and Meta-heuristic algorithm, Equality Constraints, Inequality Constraints.

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1. Introduction

To provide electricity to users, the power system comprises of utilities for generating, transmitting, and distributing. To bring down the total price of generation and to handle the unequal as well as equal margins, the ELD allots a proper generation among the available generating units fuel price. The preciseness of the fuel cost curve parameters influences how well economic dispatch problems may be solved. [1] cubic cost function models are used to overcome the constraints caused in the input and the output due to nonlinearly and the non-smoothness. The real response of thermal generators is more accurately reflected by a third-order polynomial model [2]. Numerous studies demonstrate that the cubic cost function (CCF) is a more useful way to express operating costs than the quadratic cost function Researchers using a variety of methods, including various mathematical techniques like the PSO algorithm proposed recently focused on the solution of the ELD issue with a higher-order cost function. The activities of golden jackals in forging are modelled by the GJO algorithm. The proposed analyses utilize GJO in handling the "economic load dispatch" problems (CCFELD) with four different test systems. The results were then equated with further optimization techniques reported in recent works.

The remaining portions of the study are structured as follows: ELD issues with cubic fuel cost functions are described and formulated in Section 2. In Section 3, the application of GJO for CCFELD issues is described after a brief discussion of the Golden Jackal method. Section 4 presents the outcomes observed from simulation and a summary of the conclusions. Last but not least, Section 5 provides the paper's conclusion.

2. Problem Formulation

Finding the best combination of power generators to meet equality and inequality Conditions while reducing overall generation costs is the major challenge in ELD. The practice used by the industry, which uses polynomial functions to describe the real time ELD curves of fuel cost and shows that it , significantly affects the accuracy of the economic dispatch solution. One of the most difficult tasks in ED investigations is figuring out the polynomial's order and roughly calculating its coefficients. The introduction of higher order generating cost functions can significantly improve the ELD solution. The cubic fuel cost function is expressed as follows:

“Where a,b,c,d are the fuel cost coefficients of thermal generators”.

$$F_i(P_i) = d_i P_i^3 + c_i P_i^2 + b_i P_i + a_i$$

The ELD problem's goal is to reduce fuel costs while meeting equity and inequality limitations.

$$minimize \sum_{i=1}^{N} F_i(P_i)$$

F_i (P_i) – “fuel cost function of the i-th unit”,

P_i - i-th unit's power output,

N - total generating units.

A. System Constraint

- Power balance constraints

The following equations represent the overall power generated, which incorporates both the required as well as the loss incurred to reduce cost of generation.

$$\sum_{i-1}^{N} P_i = P_D + P_L$$

“The transmission losses are expresses as”

$$\sum_{i=1}^{N}\sum_{j=1}^{N} P_i B_{ij} P_j + \sum_{i=1}^{N} B_{oi} P_i + B_{oo}$$

P_L stands for system loss while P_D stands for total load demand. A method based on the cost factor and the constant loss formula coefficient, commonly known as the B coefficient, is used to determine the system loss. The generators' loss coefficients are B_ij, B_oi, and B_oo.Generator capacity Constraints

Each unit's generation output should fall between its minimum and maximum values. For each generator, the following inequality constraint needs to be met.

$$P_i^{min} \leq P_i \leq P_i^{max}$$

Where P_i^{max} and P_i^{min} are maximum as well as the minimum generated power of i th generator.

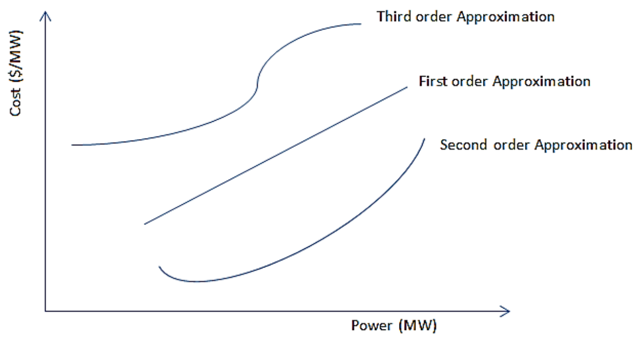


Figure 1. Cost function approximation

3. Golden Jackal Algorithm

It is based the foraging behavior of a particular species called Golden Jackal [12] the strategies used by the jackal is followed in the proposed to solve the CCFELD problems, the major steps in the algorithm are.

- Encircling the target and agitating it until it stops moving
- Rushing to the feed

The Following Shows the steps in the GJO algorithm.

A. Execution Strides of GJO Algorithm in ED Problems

Step 1. Generate initial population of prey randomly distributed across the domain of the problem.

Step 2. Evaluate each prey’s fitness values.

Step 3. Declare the optimal prey Ym (position of the male jackal), the second optimal (position of female jackal) Yfm.

Step 4. Update evading energy for each pray.

Step 5. Check evading energy for exploration phase or exploitation phase and update the Y1 and Y2 position accordingly.

Step 6. Update the prey position using equation 13.

Step 7. If the determined number of iterations are not reached then go to step 3 else go to next step.

Step 8. Output the best prey.

4. Case Studies and Simulation Results

The success of the suggested GJO strategy is assessed in this section by taking into account a variety of test scenarios. The algorithm's coding is written in “MATLAB 7.0” and run on a “Pentium Dual Core, 2.7 GHz”.. The investigation of GJO's performance in five different ELD scenarios showed that in TABLE I.

Table1. Different Cases of ELD Considered in Analysis

Test system	**Units**	**Demand**	**Transmission loss**	**Cost function**
1	6	1263 MW	✓	Quadratic
2	3	2500 MW	×	Cubic
3	3	1400 MW	✓	Cubic
4	5	1800 MW	×	Cubic
5	26	2000 MW 2900 MW	×	Cubic

A. Test System-1

"In this case study, a test system with six generating units is taken into account". There is a 1263 MW overall electricity demand. Considerations include the power balance, producing unit caps, gearbox losses, and POZs. The system information, coefficients for the loss formula, and cost coefficients were extracted from [13]. The ideal generating schedule, fuel price, and gearbox loss that GJO was able to obtain are shown in TABLE II.

The fuel cost function is minimised by the proposed GJO technique in TABLE II without breaching the system restrictions.

Table 2. Optimal Generation Schedule of Algorithms used in Test System 1

Unit power output (MW)	**PSO method [13]**	**CFA[14]**	**EMA [15]**	**KHA [16]**	**BSA[17]**	**GJO**
P1	447.4970	446.8623	447.3872	447.4150	447.4902	447.057
P2	173.3221	173.2990	173.2524	173.2917	173.3308	173.171
P3	263.4745	264.0771	263.3721	263.3559	263.4559	263.912
P4	139.0594	139.0329	138.9894	138.9646	139.0602	139.41
P5	165.4761	165.6988	165.3650	165.3759	165.4804	165.566
P6	87.1280	86.4471	87.0781	87.0417	87.1409	86.6066
Total output	1276.01	1275.4172	1275.4443	1275.4448	1275.9583	1275.36
Loss (MW)	12.9584	12.4172	12.4430	12.4449	12.9583	12.36
Total cost ($/h)	15450	15,442.6553	15443.0749	15443.0752	15449.8995	15441.9

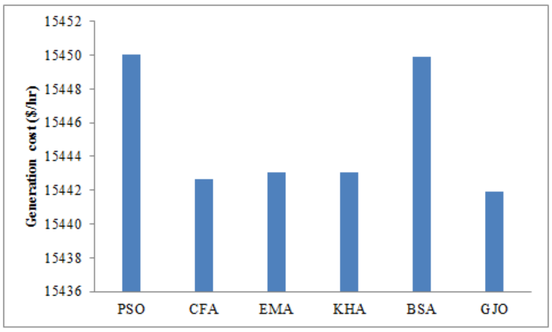


Figure 2. Comparison of Test Result for Test System 1

B. Test System 2

Table 3. contains the required data for three “generating units”, which were derived from [18]. In this instance, the total requested load Pd is 2500 MW, and the test system's gearbox power loss is disregarded. The outcomes of the GJO are contrasted with those of other techniques from the literature, which are reported in Table 4.

Table 3. Parameters of “Wollenberg’s Network System”

Gen	ai	bi	ci	di	Pmax	Pmin
P1	749.55	6.95	0.000968	1.27E-07	800	320
P2	1285	7.051	0.0007375	6.45E-08	1200	300
P3	1531	6.531	0.00104	9.98E-08	1100	275

Table 4. Results Evaluation

	Wollenberg [18]	GJO
P1	726.9000	723.626073
P2	912.8000	911.0790223
P3	860.4000	865.2949046
Demand (MW)	2500.1000	2500.00

Fuel cost ($/h)	22730.2167	22729.61

"The proposed method provides optimal solution with minimum fuel cost".

C. Test System 3

Table 5 contains a list of the generator cost coefficients, generation limitations, and B-coefficients for Liang's network (Test System-3) based on [10]. The system's load demand is 1400 MW. Table 6 shows the best generation schedule, fuel cost, and gearbox loss determined by GJO. This demonstrates that the GJO outperformed the other optimization techniques in terms of results.

Table 5. Liang's Network-System Parameters

Gen	ai	bi	ci	di	Pmax	PMing
P1	11.2	5.10238	-2.64E-03	3.33E-06	500	100
P2	-631.9	13.02	-3.06E-02	3.33E-06	500	100
P3	147.143	4.28996	3.08E-04	-1.77E-06	1000	200

Table 6. Result Evaluation

Gen	Liang [10]	SA [7]	GJO
P1	360.2000	359.7034	359.5900652
P2	406.4000	406.5985	407.3454194
P3	676.8000	677.1375	676.4684461
Demand	1400	1400	1400
Loss	43.4000	43.4395	43.4039
Fuel Cost ($/hr.)	6642.2600	6642.6628	6640.2779

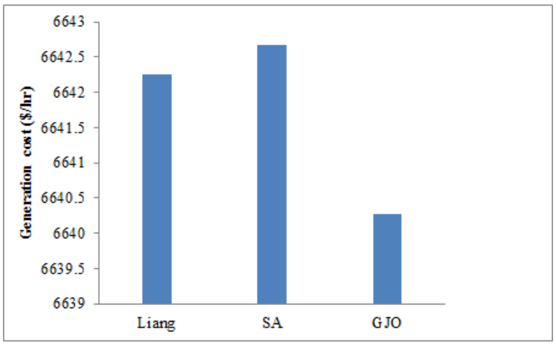


Figure 3. Evaluation of test result for test system 3

D. Test system 4

In this instance, Table 7 displays the fuel cost data for 5 units “with cubic cost functions, along with upper and lower bounds”, that were derived from [3]. In this test system, transmission power loss is disregarded and a load demand of 1800 MW is taken into account. The findings from the “genetic algorithm (GA), particle swarm optimization (PSO), and firefly algorithm (FA)”, which are displayed in TABLE VIII, are compared to those achieved for the ELD problem by the GJO. The GJO produces a power output that satisfies the requirements and has a lower overall cost than other algorithms.

Table 7. Parameters of Test system 4

Gen	ai	bi	ci	di	Pmax	PMin
P1	749.55	6.95	9.68E-04	1.27E-07	800	320
P2	1285	7.05	7.38E-04	6.45E-08	1200	300
P3	1531	6.531	1.04E-03	9.98E-08	1100	275
P4	749.55	6.95	9.68E-04	1.27E-07	800	320
P5	1285	7.05	7.38E-04	6.45E-08	1200	300

Table 8. Evaluation of ELD outcomes in Test system 4

Unit	GA[3]	PPSO[3]	FA[6]	IDHSA[8]	GJO
1	320	320	327.8004	320	320
2	343.74	343.7	341.989	343.7101	345.0884146
3	472.6	472.6	460.4217	472.5799	472.2774522
4	320	320	327.8004	320	320
5	343.74	343.7	341.989	343.71	342.6341332
Pd	1800	1800	1800	1800	1800
Fuel cost ($/hr.)	18611.07	18610.4	18610	18610.38	18609.69

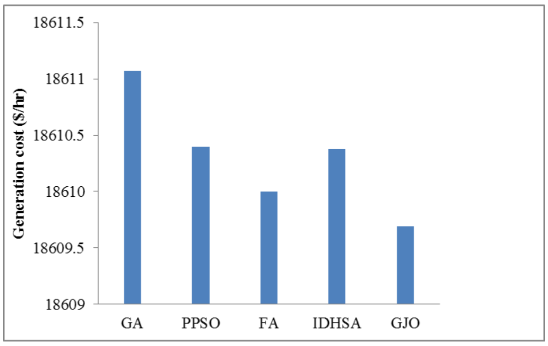


Figure 4. Comparison of Test Result for Test System 4

E. Test system 5

The test system 5, which is a sizable system, contains 26 generating units. The statistics for the cubic fuel cost function are shown in TABLE IX and cited in [19]. “In this scenario, the system load demand is 2000 MW and 2900 MW, respectively, without accounting for transmission power loss. As shown in TABLE X and TABLE XI, the results achieved by the GJO are contrasted with those from other heuristic methods”. Figure 5 displays graphic representations of the results. “The proposed method's convergence curve for this test situation is shown in Fig. 6”.

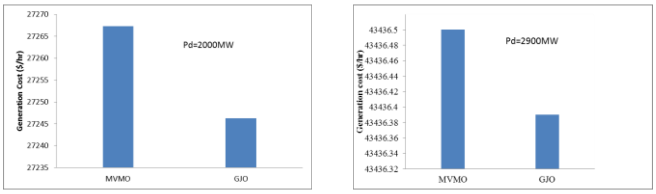
Table 9. Fuel Cost Data of 26 Generators System with Cubic Fuel Cost Function

Gen	ai	bi	ci	di	Pmax	Pmin
1	24.38	25.54	0.025	5.08E-09	2.40	12
2	24.41	25.67	0.026	-1.01E-08	2.40	12
3	24.63	25.8	0.028	1.01E-08	2.40	12
4	24.76	25.93	0.028	-5.08E-09	2.40	12
5	24.88	26.06	0.029	-5.72E-16	2.40	12
6	117.75	37.55	0.011	8.31E-08	4.00	20
7	118.1	37.66	0.012	8.56E-08	4.00	20
8	118.45	37.77	0.013	8.15E-08	4.00	20
9	118.82	37.88	0.014	8.29E-08	4.00	20
10	81.13	13.32	0.008	-5.80E-10	15.20	76
11	81.29	13.35	0.008	-5.47E-10	15.20	76
12	81.46	13.38	0.009	-5.49E-10	15.20	76
13	81.62	13.5	0.009	-5.50E-10	15.20	76
14	217.89	18	0.006	1.25E-18	25.00	100
15	218.33	18.09	0.006	-1.19E-18	25.00	100
16	218.77	18.2	0.005	2.44E-18	25.00	100
17	142.73	10.69	0.004	1.11E-15	54.30	155
18	143.02	10.71	0.004	1.03E-10	54.30	155
19	143.31	10.73	0.004	1.03E-10	54.30	155
20	143.59	10.75	0.004	1.03E-10	54.30	155
21	259.3	23	0.002	1.07E-10	69.00	197
22	259.64	23.1	0.002	1.04E-10	69.00	197
23	260.17	23.2	0.002	1.00E-10	69.00	197

24	177.05	10.86	0.001	-4.42E-19	140.00	350
25	310	7.49	0.001	-1.10E-19	100.00	400
26	311.91	7.5	0.001	-3.55E-20	100.00	400

Table 10. Generation Schedule for Power Demand: 2000 MW

Gen	MVMO [9]	GJO	Gen	MVMO [9]	GJO
1	2.3937	2.4	15	25	25
2	2.4	2.4	16	25	25
3	2.4	2.4	17	123.3045	123.183
4	2.4	2.4	18	116.6811	121.793
5	2.4	2.4	19	115.589	119.013
6	4	4	20	116.4675	115.210
7	4	4	21	68.95	69
8	4	4	22	68.95	69
9	4	4.	23	68.95	69
10	15.7337	15.2	24	346.0765	350
11	23.0998	15.2	25	400	400
12	17.7768	15.2	26	400	400
13	15.4274	15.2	Fuel cost ($/hr)	27267.3334	27246.314
14	25	25			

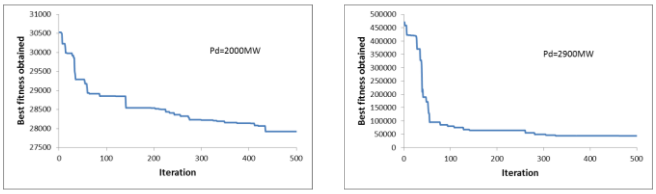


(a) (b)

Figure 2. Comparison of Test Result for Test System -5 a) Pd=2000 MW, b) Pd=2900MW

Table 11. Generation Schedule for Power Demand = 2900 MW

Gen	EEA[19]	GJO	Gen	EEA[19]	GJO
1	2.4	2.4	15	100	100
2	2.4	2.4	16	100	100
3	2.4	2.4	17	155	155
4	2.4	2.4	18	155	155
5	2.4	2.4	19	155	155
6	4	4	20	155	155
7	4	4	21	190.99	190.4603
8	4	4	22	166	163.4995
9	4	4	23	141	144.0402
10	76	76	24	350	350
11	76	76	25	400	400
12	76	76	26	400	400
13	76	76	Fuel cost ($/hr)	43436.5	43436.39
14	100	100			



(a) (b)

Figure 6. Comparison of Convergence Curve for Test System -5 a) Pd=2000 MW, b) Pd=2900 MW

5. Conclusions

The proposed research using the Golden Jackal Optimization Algorithm has put forth a suggestion and the required analysis as solution to the “ELD problem with cubic and quadratic fuel cost functions Five different simulations were run, one with gearbox loss and four without”. The result comparison of the suggested GJO with the CFA, EMA, KHA, BSA, GA, PPSO, MVMO, FA, and IDHA justifies the superiority of the GJO over them in terms of reaching a better optimal solution while fulfilling equality and inequality constraints. In general, the results demonstrate that the GJO as an efficient method for putting an end to various power system optimization problems.

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