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Ant Lion Optimization Algorithm for Solving Non-convex Economic Load Dispatch

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ABSTRACT: This paper presents a new technique to solve non-convex economic load dispatch problem using ant lion optimization (ALO) algorithm. ALO is a newly depeloved population-based search algorithm inspired hunting mechanism of ant lions. The performance of ALO algorithm is tested for economic load dispatch problem of 6-unit and 40-unit test systems with incremental fuel cost functions taking into account the valve-point effects. Simulation results shows that the proposed method has good convergence property and better in quality of solution than other algorithms reported in recent literature.

KEYWORDS: Ant lion optimization algorithm, economic load dispatch, valve-point effects.

I. INTRODUCTION

The economic load dispatch (ELD) problem is one of the fundamental issues in power system operation and control, where the total required load is distributed among the generation units in operation. The objective of ELD problem is to minimizing total generation cost while satisfying load and operational constraints [1]. Various methods and investigations are being carried out until date in order to produce a significant saving in the operational cost. Generally, fuel cost function of a generator is represented by single quadratic function, but a quadratic function is not able to show the practical behavior of generator. The ELD problem is a non-convex and nonlinear optimization problem. Due to ELD complex and nonlinear characteristics, it is hard to solve the problem using classical optimization methods such as gradient method, lambda iteration method, Newton's method, linear programming, Interior point method and dynamic programming [2].

In the past years many optimization algorithms are being developed to solve ELD problems such as genetic algorithm (GA) [3, 4], tabu search (TS) [5], simulated annealing (SA) [6], neural network (NN) [7, 8], evolutionary programming (EP) [9]-[11], biogeography-based optimization (BBO) [12], artificial bee colony (ABC) [13], and particle swarm optimization (PSO) [14]-[18].

Recently, a new meta-heuristic search algorithm, called ant lion optimization (ALO), has been developed by Mirjalili in 2015 [19]. In this paper, ALO algorithm has been used to solve ELD problem considering valve-point effect and transmission loss. The feasibility of the proposed method has been demonstrated on 6-unit and 40-unit test systems. The results obtained with the proposed algorithms were compared with other optimization results reported in literature.

II. PROBLEM FORMULATION

The main purpose of the ELD problem is to determine the optimal combination of power plants that minimize the total cost of generation while meeting the equality and inequality constraints. The fuel cost curve for each unit is assumed to be approximated by segments of quadratic functions of the active power output of the generator. For a given power system network, the problem may be explained as optimization (minimization) of total fuel cost as defined by (1) under a set of operating constraints.

$$F_T = \sum_{i=1}^{n} F_i(P_i) = \sum_{i=1}^{n} \left(a_i P_i^2 + b_i P_i + c_i \right) \quad (1)$$

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where F_T is total fuel cost of generation in power system ($/hr), a_i, b_i, and c_i are the cost coefficient of the i-th generator, P_i is the power generated by the i-th unit and n indicates the number of generators.

2.1. Active Power Balance Equation

For the balance of power, an equality constraint should be satisfied. The total generated power should be the same as total load demand plus the total transmission loss.

$$P_D = \sum_{i=1}^{n} P_i - P_{Loss} \tag{2}$$

where P_D is the total load demand and P_{Loss} is total transmission loss. The transmission losses P_{Loss} can be calculated by using B matrix technique and is defined by (3) as,

$$P_{Loss} = \sum_{i=1}^{n}\sum_{j=1}^{n} P_i B_{ij} P_j + \sum_{i=1}^{n} B_{0i} P_i + B_{00} \tag{3}$$

where B_{ij} is coefficient of transmission losses and the B_{0i} and B_{00} is matrix for loss in transmission which are constant under certain assumed conditions.

2.2. Minimum and Maximum Power Limits

The output power of each generator should lie between minimum and maximum limits, so that

$$P_i^{\min} \le P_i \le P_i^{\max} \ \text{ for } \ i = 1,2,\cdots,n \tag{4}$$

where $P_i^{\min}$ and $P_i^{\max}$ are the minimum and maximum outputs of the i-th generator, respectively.

2.3. Valve-Point Effects

The fuel cost function with the valve-point effects of the thermal generating unit are taken into consideration in the ELD problem by superimposing the basic quadratic fuel-cost characteristics with the rectified sinusoidal component as follows [15]:

$$F_T = \sum_{i=1}^{n} F(P_i) = \sum_{i=1}^{n} \left(a_i P_i^2 + b_i P_i + c_i + \left| e_i \times \sin\left(f_i \times \left(P_i^{\min} - P_i \right) \right) \right| \right) \tag{5}$$

where F_T is the fuel cost function of generating unit in ($/hr), e_i, f_i are fuel cost coefficients of the i-th generating unit reflecting valve-point effects.

III. ANT LION OPTIMIZATION (ALO)

Ant Lion Optimizer (ALO) is a novel nature-inspired algorithm proposed by Sayedali Mirjalili in 2015 [19]. The ALO algorithm emulates the hunting mechanism of antlions in nature. There are five main steps of the algorithm such that random walk of ants, building traps, entrapment of ants in traps, catching preys, and re-building traps. Antlions belong to the Myrmeleontidae family and Neuroptera order (net-winged insect). The lifecycle of antlions include two main phases: larvae and adult. They mostly hunt in larvae and undergo reproduction during adult. An antlion larvae digs a cone-shaped pit in sand by moving along a circular path and throwing out sands by using massive jaws. After digging the trap, the larvae hides underneath the bottom of the cone and waits for insect to be trapped in the pit. When a prey in caught, it will be pulled and consumed. After that, the antlions throw the leftovers outsode the pit and improve the pit for the next hunt.

3.1. Random Walk of Ants

The ALO algorithm imitates the interaction between ant lions and ants in the trap. For such interaction models, ants are required to move over the search space and antlions are allowed to hunt them and become fitter using traps. Since ants move stochastically in nature when searching for food, a random walk is chosen for the modeling ants' movement as follows:

$$X(t) = [0, cums(2r(t_1) - 1, cums(2r(t_2) - 1, \ldots, cums(2r(t_n) - 1] \tag{6}$$

where *cums* calculates the cumulative sum and *r(t)* is defined as follows:

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$$r(t) = \left\{ \begin{bmatrix} 1, & if \ \ rand > 0.5 \\ 0, & if \ rand \leq 0.5 \end{bmatrix} \right\} \quad (7)$$

The position of ants are stored and used during optimization process in the following matrix:

$$M_{ant} = \begin{bmatrix} ant_{1,1} & ant_{1,2} & \dots & ant_{1,d} \\ ant_{2,1} & ant_{2,2} & \dots & ant_{2,d} \\ \vdots & \vdots & & \vdots \\ ant_{n,1} & ant_{n,2} & \dots & ant_{n,d} \end{bmatrix} \quad (8)$$

where, M_{ant} is matrix to save the position of each ant, ant_{ij} is value of *j*-th variable (dimension) of *i*-th ant, *n* is number of ants, and *d* is number of variables.

During optimization process, matrix M_{ant} will save the position of all ants (variables of all solutions). Random walk of ants are being normalized to keep them moving within the search space using the following equation:

$$X_i^t = \frac{(X_i^t - a_i) \times (d_i - c_i^t)}{(d_i^t - a_i)} + c_i \quad (9)$$

where a_i indicates the minimum of random walk of *i-th* variable, d_i is the maximum of random walk in *i-th* variable, c_i^t is the minimum of *i-th* variable at *t-th* iteration, and d_i^t indicates the maximum *i-th* variable at *t-th* iteration.

3.2. Trapping in Ant Lion's Pits

The following equations are used to represent mathematically model of antlions pits.

$$c_i^t = Antlion_j^t + c^t \quad (10)$$

$$d_i^t = Antlion_j^t + d^t \quad (11)$$

where c^t is the minimum of all variables at *t-th* iteration, d^t indicates the vector including the maximum of all variables at *t-th* iteration, c_i^t is the minimum of all variables for *i-th* ant, d_i^t is the maximum of all variables for *i-th* ant, and $Antlion_j^t$ shows the position of the selected *j-th* antlion at *t-th* iteration.

3.3. Building Trap

Ant lion's hunting ability is modeled by roulette wheel operator for selecting ant lions based on their fitness during optimization. This mechanism gives great probabilities to the fitter ant lions for catching preys.

3.4. Sliding Ants towards Ant Lion

Ant lions are capable to build traps proportional to their fitness and ants are necessary to move randomly. Once the ant is in the trap, ant lions will shoot sands outwards the center of the pit. This behavior slides down the trapped ant in the trap. The radius of ants's random walks are represented as (12) and (13),

$$c^t = \frac{c^t}{I} \quad (12)$$

$$d^t = \frac{d^t}{I} \quad (13)$$

where *I* is a ratio, c^t is the minimum of all variables at *t-th* iteration, d^t indicates the vector including the maximum of all variables at *t-th* iteration.

These equations reduce the radius of updating ants' positions and mimics sliding manner of prey inside the pits.

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3.5. Catching Prey and Re-Building the Pit

Last phase of hunt is when ant reaches the bottom of the pit and being trapped in the ant lion's jaw. The ant lion attracts the ant inside the sand and consumes its body. It is assumed that catching prey occur when ants become fitter (goes inside sand) than its corresponding ant lion. Ant lion is required to modernize its location to the latest position of the hunted ant to improve its chance of catching new prey.
It is represented by the following equation:

$$Antlion_j^t = Ant_i^t,\ if \quad f(Ant_i^t) > f(Antlion_j^t) \tag{14}$$

where *t* is the current iteration, $Antlion_j^t$ shows the position of selected *j-th* antlion at *t-th* iteration, and Ant_i^t indicates the position of *i-th* ant at *t-th* iteration.

3.6. Elitism

The best ant lion achieved each iteration is kept as elite, the fittest ant lion. The fittest ant lion should be able to affect the movements of all ants during iterations. It is assumed that every random walks of ants around a chosen ant ion by the roulette wheel and the elite instantaneously as follows:

$$Ant_i^t = \frac{R_A^t + R_E^t}{2} \tag{15}$$

where R_A^t is the random walk around the antlion selected by the roulette wheel at *t-th* iteration, R_E^t is the random walk around the elite at *t-th* iteration, and Ant_i^t indicates the position of *i-th* ant at *t-th* iteration.
The pseudo code of the ALO algorithm is shown in Table 1.

Table 1 Pseudo-code of ALO

Ant Lion Optimizer (ALO)
Initialize the first population of ant and ant lions randomly
Calculate the fitness of ants and antlions
Find the best antlions and assume it as the elite (best solution)
while *the end criterion is not satisfied*
for *every ant*
Select an ant lion using Roulette wheel
Update c and d using equations (12) & (13)
Create a random walk and normalize it using equations (6) & (12)
Update the position of ant using equation (15)
end for
Calculate the fitness of all ants
Replace an ant lion with its corresponding ant become fitter using equation (14)
Update elite if an ant lion become fitter than the elite
end while
Return elite

IV. SIMULATION RESULTS

To verify the feasibility of the proposed method, two different power systems were tested: (1) 6-unit system with valve-point effects and transmission losses, and (2) 40-unit system with valve-point effects and transmission losses are neglected.

Test Case 1: 6-unit system

The system consists of six thermal generating units with valve-point effects. The total load demand on the system is 1263 MW. The parameters of all thermal units are presented in Table 2 [14].

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Table 2 Generating unit capacity and coefficients (6-units)

Unit	$P_i^{\min}$ (MW)	$P_i^{\max}$ (MW)	a	b	c	e	f
1	100	500	0.0070	7.0	240	300	0.035
2	50	200	0.0095	10.0	200	200	0.042
3	80	300	0.0090	8.5	220	200	0.042
4	50	150	0.0090	11.0	200	150	0.063
5	50	200	0.0080	10.5	220	150	0.063
6	50	120	0.0075	12.0	190	150	0.063

The transmission losses are calculated by *B* matrix loss formula which for 6-unit system is given as:

$$B_{ij} = \begin{bmatrix} 0.0017 & 0.0012 & 0.0007 & -0.0001 & -0.0005 & -0.0002 \\ 0.0012 & 0.0014 & 0.0009 & 0.0001 & -0.0006 & -0.0001 \\ 0.0007 & 0.0009 & 0.0031 & 0.0000 & -0.0010 & -0.0006 \\ -0.0001 & 0.0001 & 0.0000 & 0.0024 & -0.0006 & -0.0008 \\ -0.0005 & -0.0006 & -0.0010 & -0.0006 & 0.0129 & -0.0002 \\ -0.0002 & -0.0001 & -0.0006 & -0.0008 & -0.0002 & 0.0150 \end{bmatrix}$$

$$B_{0i} = 1.0e^{-3} * [-0.3908 \; -0.1297 \; 0.7047 \; 0.0591 \; 0.2161 \; -0.6635]$$

$$B_{00} = 0.0056$$

The obtained results for the 6-unit system using the ALO algorithms are given in Table 3 and the results are compared with other methods reported in literature, including GA, PSO, PSO-LRS, NPSO, and NPSO-LRS [18]. It can be observed that the proposed algorithm can get total generation cost of 15,443 $/hr and power losses of 12.4450 MW, which is the best solution among all the methods. Note that the outputs of the generators are all within the generator's permissible output limit.

Table 3 Comparison of the best results of each methods (P_D = 1263 MW)

Unit Output	GA	PSO	PSO-LRS	NPSO	NPSO-LRS	**ALO**
P1 (MW)	474.8066	447.4970	447.4440	447.4734	446.9600	447.3990
P2 (MW)	178.6363	173.3221	173.3430	173.1012	173.3944	173.2408
P3 (MW)	262.2089	263.0594	263.3646	262.6804	262.3436	263.3812
P4 (MW)	134.2826	139.0594	139.1279	139.4156	139.5120	138.9796
P5 (MW)	151.9039	165.4761	165.5076	165.3002	164.7089	165.3914
P6 (MW)	74.1812	87.1280	87.1698	87.9761	89.0162	87.0529
Total power output (MW)	1276.03	1276.01	1275.95	1275.95	1275.94	1275.445
Total generation cost ($/hr)	15,459	15,450	15,450	15,450	15,450	15,443
Power losses (MW)	13.0217	12.9584	12.9571	12.9470	12.9361	12.4450

Test Case 2: 40-unit system

This system consisting of 40 generating units and the input data for 40-generator system is given in Table 4 [10]. The total demand is set to 10,500 MW.

The obtained results for the 40-unit system using the ALO algorithms are given in Table 5 and the results are compared with other methods reported in literature, including PSO, PPSO, and APPSO [20]. It can be observed that the proposed algorithm can get total generation cost of 120977.68 $/hr, which is the best solution among all the methods. These

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results show that the proposed methods are feasible and indeed capable of acquiring better solution. The optimal dispatches of the generators are listed in Table 5. Also note that all generators' outputs are within its permissible limits.

Table 4 Generating unit capacity and coefficients (40-units)

Unit	P_{min} (MW)	P_{max} (MW)	a	b	c	e	f
1	36	114	0.00690	6.73	94.705	100	0.084
2	36	114	0.00690	6.73	94.705	100	0.084
3	60	120	0.02028	7.07	309.54	100	0.084
4	80	190	0.00942	8.18	369.03	150	0.063
5	47	97	0.01140	5.35	148.89	120	0.077
6	68	140	0.01142	8.05	222.33	100	0.084
7	110	300	0.00357	8.03	287.71	200	0.042
8	135	300	0.00492	6.99	391.98	200	0.042
9	135	300	0.00573	6.60	455.76	200	0.042
10	130	300	0.00605	12.9	722.82	200	0.042
11	94	375	0.00515	12.9	635.20	200	0.042
12	94	375	0.00569	12.8	654.69	200	0.042
13	125	500	0.00421	12.5	913.40	300	0.035
14	125	500	0.00752	8.84	1760.4	300	0.035
15	125	500	0.00708	9.15	1728.3	300	0.035
16	125	500	0.00708	9.15	1728.3	300	0.035
17	220	500	0.00313	7.97	647.85	300	0.035
18	220	500	0.00313	7.95	649.69	300	0.035
19	242	550	0.00313	7.97	647.83	300	0.035
20	242	550	0.00313	7.97	647.81	300	0.035
21	254	550	0.00298	6.63	785.96	300	0.035
22	254	550	0.00298	6.63	785.96	300	0.035
23	254	550	0.00284	6.66	794.53	300	0.035
24	254	550	0.00284	6.66	794.53	300	0.035
25	254	550	0.00277	7.10	801.32	300	0.035
26	254	550	0.00277	7.10	801.32	300	0.035
27	10	150	0.52124	3.33	1055.1	120	0.077
28	10	150	0.52124	3.33	1055.1	120	0.077
29	10	150	0.52124	3.33	1055.1	120	0.077
30	47	97	0.01140	5.35	148.89	120	0.077
31	60	190	0.00160	6.43	222.92	150	0.063
32	60	190	0.00160	6.43	222.92	150	0.063
33	60	190	0.00160	6.43	222.92	150	0.063
34	90	200	0.00010	8.95	107.87	200	0.042
35	90	200	0.00010	8.62	116.58	200	0.042
36	90	200	0.00010	8.62	116.58	200	0.042
37	25	110	0.01610	5.88	307.45	80	0.098
38	25	110	0.01610	5.88	307.45	80	0.098
39	25	110	0.01610	5.88	307.45	80	0.098
40	242	550	0.00313	7.97	647.83	300	0.035

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Table 5 Comparison of the best results of each methods (P_D = 10,500 MW)

Unit power output	PSO	PPSO	APPSO	**ALO**
P1 (MW)	113.116	111.601	112.579	114.0000
P2 (MW)	113.010	111.781	111.553	113.6096
P3 (MW)	119.702	118.613	98.751	119.3709
P4 (MW)	81.647	179.819	180.384	139.1894
P5 (MW)	95.062	92.443	94.389	96.6380
P6 (MW)	139.209	139.846	139.943	121.7497
P7 (MW)	299.127	296.703	298.937	262.5558
P8 (MW)	287.491	284.566	285.827	286.2295
P9 (MW)	292.316	285.164	298.381	295.1444
P10 (MW)	279.273	203.859	130.212	168.4734
P11 (MW)	169.766	94.283	94.385	96.3017
P12 (MW)	94.344	94.090	169.583	302.0755
P13 (MW)	214.871	304.830	214.617	209.6986
P14 (MW)	304.790	304.173	304.886	411.1092
P15 (MW)	304.563	304.467	304.547	152.9018
P16 (MW)	304.302	304.177	304.584	372.0743
P17 (MW)	489.173	489.544	498.452	488.3313
P18 (MW)	491.336	489.773	497.472	494.0121
P19 (MW)	510.880	511.280	512.816	535.3915
P20 (MW)	511.474	510.904	548.992	547.4823
P21 (MW)	524.814	524.092	524.652	549.6893
P22 (MW)	524.775	523.121	523.399	504.5833
P23 (MW)	525.563	523.242	548.895	545.4597
P24(MW)	522.712	524.260	525.871	461.1043
P25 (MW)	503.211	523.283	523.814	545.1826
P26 (MW)	524.199	523.074	523.565	548.4700
P27 (MW)	10.082	10.800	10.575	10.7057
P28 (MW)	10.663	10.742	11.177	12.8331
P29 (MW)	10.418	10.799	11.210	11.3522
P30 (MW)	94.244	94.475	96.178	60.3032
P31(MW)	189.377	189.245	189.999	189.9931
P32 (MW)	189.796	189.995	189.924	188.1960
P33 (MW)	189.813	188.081	189.714	189.1677
P34 (MW)	199.797	198.475	199.284	199.3021
P35 (MW)	199.284	197.528	199.599	193.9630
P36 (MW)	198.165	196.971	199.751	197.9512
P37 (MW)	109.291	109.161	109.973	107.1951
P38 (MW)	109.087	109.900	109.506	109.8709
P39 (MW)	109.909	109.855	109.363	109.8678
P40 (MW)	512.348	510.984	511.261	438.4709
Total generation cost ($/h)	122323.97	121788.22	122044.63	120977.68

V. CONCLUSION

In this paper, ALO algorithm has been applied to solve ELD problem of generating units considering the valve-point effects. The proposed algorithm has provided the global solution in the 6-unit and 40-unit generator systems and the better solution than the previous studies reported in literature. The advantage of proposed technique is its simplicity, reliability and efficiency for practical applications.

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