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Ant Lion Optimization Algorithm For Environmental/Economic Dispatch Problem

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--***ABSTRACT***--
This paper presents the use of a recent developed algorithm inspired by the hunting mechanism of antlions in nature, called ant lion optimization (ALO) algorithm for solving combined environmental economic dispatch (CEED) problem in power systems considering valve-point effect and transmission loss. The main objective of the proposed method is the simultaneous minimization of the generation cost and pollutant emission with considering the weigthing factor while satisfying load demand and operational constraints. The performance of the proposed algorithm has been tested on 10-generator system and the results were compared with other methods reported in recent literature. The results show that the proposed algorithm is capable of producing better results.
Keywords:*Economic dispatch, emission dispatch, combined environmental economic dispatch, ant lion optimization, valve-point effect.*

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I. INTRODUCTION

The economic dispatch (ED) has become a vital task for proper operation and planning of power system. The objective of ED problem of electric power generation is to schedule the committed generating unit outputs so as to meet the load demand at minimum operating cost while satisfying all generating units and the equality and inequality constraints. This makes a large-scale highly nonlinear constrained optimization problem. Therefore, recently most of the researchers made studies for finding the most suitable power values produced by the generators depending on fuel costs [1, 2]. In these studies, they produced successful results by using various optimization algorithms. Despite the fact that the traditional ED can optimize generator fuel costs, it still cannot produce a solution for environmental pollution due to the excessive emission of fossil fuels [3-5].

Currently, most of the energy production is done by thermal sources. Thermal power plant is one of the most important sources of carbon dioxide (CO_2), sulfur dioxide (SO_2) and nitrogen oxides (NO_x) which create atmospheric pollution [6]. Emission control has received increasing attention owing to increased concern over environmental pollution caused by fossil based generating units and the enforcement of environmental regulations in recent years [7]. A number of studies have emphasized the importance of controlling pollution in electric power systems [8].

In the field of power generation dispatch, combined environmental economic dispatch (CEED) has been proposed which simultaneously minimizes both fuel cost and pollutant emissions. When minimized emissions, fuel costs may be unacceptably high or when fuel costs are minimized, emissions may be high. A number of methods have been presented to solve CEED problems such as simplified recursive method [9], genetic algorithm [10-12], simulated annealing [13, 14], differential evolution [15], biogeography based optimization [16], particle swarm optimization [17, 18], and artificial bee colony algorithm [19, 20].

Recently, a new meta-heuristic search algorithm, called ant lion optimization (ALO), has been developed by Mirjalili in 2015 [21]. In this paper, ALO algorithm has been used to solve CEED problem considering valve-point effect and transmission loss. Feasibility of the proposed method has been demonstrated on ten generator system. The results obtained with the proposed algorithm were analyzed and compared with other optimization results reported in literature.

II. PROBLEM FORMULATION

The CEED problem targets to find the optimal combination of load dispatch of generating units and minimizes both fuel cost and emission while satisfying the total power demand. Therefore, CEED consists of two objective functions, which are economic and emission dispatches. Then both of these functions are combined into single objective function to solve the problem.The CEED problem can be formulated as follows [11]:

$$F_T = Min\ f\left(FC, EC\right) \tag{1}$$

where F_T is the total generation cost of the system, *FC* is the total fuel cost of generators and *EC* is the total emission of generators.

2.1 Minimization of Fuel Cost

Total fuel cost of a power generating station considering the valve-point effects can be expressed as:

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

where P_i is the power generation of the *i*th unit; a_i, b_i, c_i, e_i, and f_i are fuel cost coefficients of the *i*-th generating unit; and *N* is the number of generating units.

2.2 Minimization of Emission

The classical ED problem can be obtained by the amount of active power to be generated by the generating units at minimum fuel cost, but it is not considered as the amount of emissions released from the burning of fossil fuels. Total amount of emissions such as SO_2 or NO_X depends on the amount of power generated by until and it can be defined as the sum of quadratic and exponential functions and can be stated as [11]:

$$EC = \sum_{i=1}^{N}\left(\alpha_i P_i^2 + \beta_i P_i + \gamma_i + \eta_i \exp(\delta_i P_i)\right) \tag{3}$$

where α_i, β_i, γ_i, η_i and δ_i are emission coefficients of the *i*-th generating units.

2.3 Combined Environmental Economic Dispatch (CEED)

The bi-objective combined environmental economic dispatch problem is converted into single optimization problem by introducing weight factor and the price penalty factor as follows:

$$F_T = (w_1 * FC + w_2 * h * EC) \tag{4}$$

under the following condition,

$$w_1 + w_2 = 1 \text{ and } w_1, w_2 \geq 0 \tag{5}$$

where w_1, w_2 are weight factor and *h* indicate the price penalty factor.

2.4 Problem Constraints

There are two constraints in the CEED problem which are power balance constraint and maximum and minimum limits of power generation output constraint.

Power balance constraint:

$$\sum_{i=1}^{N} P_i = P_D + P_L \tag{6}$$

$$P_L = \sum_{i}^{N}\sum_{j}^{N} B_{ij} P_i P_j \tag{7}$$

Generating capacity constraint:

$$P_{i\min} \leq P_i \leq P_{i\max} \tag{8}$$

where P_D is total demand of system (MW); P_L is total power loss; $P_{i\ min}$ and $P_{i\ max}$ are minimum and maximum generation of unit *i* (MW); and B_{ij} is coefficients of transmission loss.

III. ANT LION OPTIMIZATION (ALO)

Ant Lion Optimizer (ALO) is a novel nature-inspired algorithm proposed by Sayedali Mirjalili in 2015 [21]. 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:

$$X(t) = [0, cums(2r(t_1) - 1, cums(2r(t_2) - 1, \ldots, cums(2r(t_n) - 1] \quad (9)$$

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

$$r(t) = \left\{ \begin{Bmatrix} 1, \; if \;\; rand > 0.5 \\ 0, \; if \; rand \le 0.5 \end{Bmatrix} \right. \quad (10)$$

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

$$M_{ant} = \begin{bmatrix} ant_{1,1} & ant_{1,2} & \ldots & ant_{1,d} \\ ant_{2,1} & ant_{2,2} & \ldots & ant_{2,d} \\ \vdots & \vdots & & \vdots \\ ant_{n,1} & ant_{n,2} & \ldots & ant_{n,d} \end{bmatrix} \quad (11)$$

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:

$$X_i^t = \frac{(X_i^t - a_i) \times (d_i - c_i^t)}{(d_i^t - a_i)} + c_i \quad (12)$$

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.

$$c_i^t = Antlion_j^t + c^t \quad (13)$$

$$d_i^t = Antlion_j^t + d^t \quad (14)$$

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

The ant lion's hunting ability is modeled by roulette wheel operator to select 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

The ant lion can build a trap that is comparable to the fitness and ants needed 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 (15) and (16),

$$c^t = \frac{c^t}{I} \quad (15)$$

$$d^t = \frac{d^t}{I} \quad (16)$$

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.

3.5 Catching Prey and Re-Building the Pit

The last stage of hunting is when the ants reach the bottom of the hole and are trapped in the jaws of the ant lion. The ant lion attracts the ant inside the sand and consumes its body. Assumed that catching prey occur when ants

become fitter (goes inside sand) than its corresponding ant lion. Ant lions are required to modernize their location to the last position of ants being hunted to increase the chances of catching new prey.
It is represented by the following equation:

$$Antlion_j^t = Ant_i^t\,,\ if\quad f(Ant_i^t) > f(Antlion_j^t) \qquad (17)$$

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 succeed 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. Assummed that every random walks of ants around a chosen ant ion by the roulette wheel and the elite instantaneously as follows:

$$Ant_i^t = \frac{R_A^t + R_E^t}{2} \qquad (18)$$

where R_A^t indicates the random walk around the ant lion 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 (15) & (16)
Create a random walk and normalize it using equations (9) & (12)
Update the position of ant using equation (18)
end for
Calculate the fitness of all ants
Replace an ant lion with its corresponding ant become fitter using equation (17)
Update elite if an ant lion become fitter than the elite
end while
Return elite

IV. SIMULATION RESULTS

The proposed techniques have been applied to a test power system consists of ten generators at 2000 MW power demand. Generation unit data has been taken from [22]. Simulations were performed in MATLAB R2010a environment on a PC with a 3 GHz processor.

4.1 Case I: Optimization of each of the two objectives individually

In this case, both the fuel cost and the gas emission are minimized separately as a single objective functions. Minimizing each objective function individually is executed by giving full weight to the function to be optimized and neglecting others. Table 2 presents the results of economic dispatch when the objective is minimizing just the fuel cost (w_1=1, w_2=0). The fuel cost and the gas emission output of 10 unit system for 2000 MW are 111289.3362 $/h and 4405.8689 lb/h respectively when the fuel cost is the optimized function. The power losses are 87.0079 MW.
Table 3, presents the results of economic emission dispatch when the objective is minimizing just the gas emission (w_1=0, w_2=1). The fuel cost and the gas emission output of 10 unit system for 2000 MW are 116263.7831 $/h and 3840.8472 lb/h respectively when the gas emission is the optimized function. The power losses are 81.4492 MW.

Table 2: Comparison of the best fuel cost results of each methods (P_D = 2000 MW)

Unit Output	ABC_PSO [22]	DE [15]	SA [14]	**ALO**
P1 (MW)	55	55	54.9999	55.0000
P2 (MW)	80	79.89	80	79.9885
P3 (MW)	106.93	106.8253	107.6263	101.1444

P4 (MW)	100.5668	102.8307	102.5948	112.6896
P5 (MW)	81.49	82.2418	80.7015	79.8951
P6 (MW)	83.011	80.4352	81.1210	78.2924
P7 (MW)	300	300	300	299.9980
P8 (MW)	340	340	340	339.9999
P9 (MW)	470	470	470	469.9999
P10 (MW)	470	469.8975	470	470.0000
Losses (MW)	87.0344	-	87.0434	87.0079
Fuel cost ($/h)	111500	111500	111498.6581	111289.3362
Emission (lb/h)	4571.2	4581	4584.8366	4405.8689

4.2 Case II: *Optimization of the fuel cost and gas emission simultaneously*

In this case, the problem as multi-objective; two objectives are minimized simultaneously (the fuel cost and the gas emission objectives) by using the weighted factors w_1 = 0.5 and w_2 = 0.5. The multi-objective optimization problem can be converted to a single objective optimization problem by introducing weighted factors. Table 4, presents the results of combined environmental economic dispatch when the objective is minimizing both fuel cost and the gas emission. The fuel cost and the gas emission output of 10 unit system for 2000 MW are 113409.8128 $/h and 4117.2719 lb/h respectively. The power losses are 83.7851 MW.

Table 3: Comparison of the best emission results of each methods (P_D = 2000 MW)

Unit Output	ABC_PSO [22]	DE [15]	SA [14]	**ALO**
P1 (MW)	55	55	54.9999	55.0000
P2 (MW)	80	80	80	77.1120
P3 (MW)	81.9604	80.5924	76.6331	80.9084
P4 (MW)	78.8216	81.0233	79.4332	88.7195
P5 (MW)	160	160	160	160.0000
P6 (MW)	240	240	240	240.0000
P7 (MW)	300	292.7434	287.9285	295.6500
P8 (MW)	292.78	299.1214	301.4146	294.6069
P9 (MW)	401.8478	394.5147	412.4386	389.9454
P10 (MW)	391.2096	398.6383	388.9348	399.5071
Losses (MW)	81.5879	-	81.7827	81.4492
Fuel cost ($/h)	116420	116400	116386	116263.7831
Emission (lb/h)	3932.3	3923.4	3935.9769	3840.8472

Table 4: Comparison of CEED results of each methods (P_D = 2000 MW)

Unit Output	ABC_PSO [22]	DE [15]	NSGA-II [15]	**ALO**
P1 (MW)	55	54.9487	51.9515	55.0000
P2 (MW)	80	74.5821	67.2584	79.9716
P3 (MW)	81.14	79.4294	73.6879	86.5561
P4 (MW)	84.216	80.6875	91.3554	83.4382
P5 (MW)	138.3377	136.8551	134.0522	142.6408
P6 (MW)	167.5086	172.6393	174.9504	160.3467
P7 (MW)	296.8338	283.8233	289.435	298.3295
P8 (MW)	311.5824	316.3407	314.0556	323.9501
P9 (MW)	420.3363	448.5923	455.6978	426.4291
P10 (MW)	449.1598	436.4287	431.8054	427.1231
Losses (MW)	84.1736	-	-	83.7851
Fuel cost ($/h)	113420	113480	113540	113409.8128
Emission (lb/h)	4120.1	4124.9	4130.2	4117.2719

V. CONCLUSION

In this paper, ALO algorithm has been applied to solve CEED problem of generating units considering the valve-point effect and transmission losses. The proposed technique has provided the global solution in the 10-generator system 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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