Approach of economic-emission load dispatch using Ant Lion Optimizer

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***Abstract*— *To solve the problem of the economic emission load dispatch (EELD) is necessary minimize the total cost of fuel consumption and carbon emission. In this study is applied the ant lion optimizer (ALO) to this problem. The cost function and emission function with their respective restrictions are being using. To present the results this proposal is applied in IEEE 30 bus system that consists of six thermal units. The results for this case study with the application of ant lion with all generators on with demand being met, the total fuel cost is 48915.36652 ($/h). The results this method can be compared with another metaheuristic algorithms and helps the plant operators in the decision making of preventive maintenance.*

Keywords*— *Ant lion Optimizer, EELD, Power Plants.

I. INTRODUCTION

The Thermal Power Plant (TPP) operation is dependent upon incineration of fossil fuel which generates sulfur dioxide (SO_2), carbon dioxide (CO_2) and nitrogen oxides (NO_x) which create atmospheric pollution. Reduce the emission level and total cost of generation and at the same time accomplishing the demand for electricity from the power plant is is the goal of economic emission load dispatch (EELD). To solve the EELD problem is necessary minimize the total cost of fuel consumption and carbon emissions (De, Das, Mandal, & Mandal, 2018; Moraes, Bezerra, Moya Rodríguez, Nascimento, & Leite, 2018). The problem is formulated as a multiobjective economic emission load dispatch (EELD) problem in which both the objectives (emission and economy) have to be minimized (Chopra, Kumar, & Mehta, 2016). This is a complex problem to solve because of its large size, a nonlinear objective function and a wide number of restrictions (Bhattacharya & Chattopadhyay, 2010).

Various evolutionary, heuristic and meta-heuristics optimization algorithms have been developed such as: Grey Wolf Optimization (GWO) (Chopra et al., 2016; Hong, MH, & Mohd Rusllim, 2014), non-dominated sorting genetic algorithm (NSGA-II) (Basu, 2008; Moraes et al., 2018), hybrid genetic algorithm (Thenmozhi & Mary, 2004), Tabu Search Algorithm (Li, Yang, Tseng, Wang, & Lim, 2018), Simulated annealing (Júnior, Nunes, Nascimento, Rodríguez, & Leite, 2017; Ziane, Benhamida, & Graa, 2017), Neural Networks (Deng, He, & Zeng, 2017), Harmony Search Algorithm (El Ela, El-Sehiemy, Shaheen, & Shalaby, 2017), particle swarm optimization (De et al., 2018), Differential Evolution (Jebaraj, Venkatesan, Soubache, & Rajan, 2017), Ant Colony Optimization (Zhou et al., 2017), Biogeography-Based Optimization (Ma, Yang, You, & Fei, 2017), genetic algorithm controlled by fuzzy logic (Song, Wang, Wang, & Johns, 1997).

This research use the emission function and economic function in the multiobjective optimization ALO, with restrictions.

II. MATERIAL AND METHODS

To solve a problem of EELD, two important objectives in an electrical power system must be considered; they are: environmental, and economy impacts (Basu, 2014).

2.1 Economic Load Dispatch

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The fuel cost is considered as an essential criterion for economics analysis in ELD. The most simplified cost function of each generator can be assumed to be approximated by a quadratic function of generator power output P_i (Ghosh, Chakraborty, Bhowmik, & Bhattacharya, 2017; Jebaraj et al., 2017):

$$F1(P_i) = \sum_{i=1}^{N} (a_i + b_i P_i + c_i P_i^2) \quad \$/h \qquad (1)$$

where a_i, b_i and c_i are the fuel cost coefficients of the ith unit generating, N the number of generators and P_i the active power of each generator. Fig. 1 illustrates the fuel cost curve without valve-point effects and emissions.

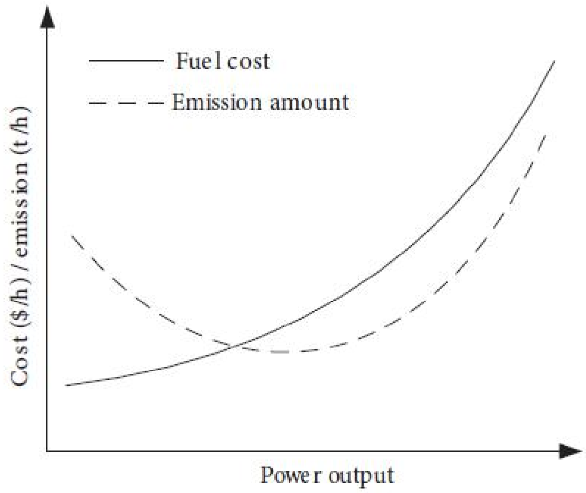

Fig.1: Fuel cost and emission function of the thermal generator.
Source: (Gitizadeh & Ghavidel, 2014)

2.2 Economic Emission Dispatch

Emissions can be represented by a function, that links emissions with power generated by each unit. The emission function in kg/h, which normally represents the emission of SO2 and NOx, is a function of the power output of the generator, and it can be expressed as follows (Swain, Sarkar, Meher, & Chanda, 2017):

$$F2(P_i) = \sum_{i=1}^{N} (d_i + e_i P_i + f_i P_i^2) \quad kg/h \qquad (2)$$

Where d_i, e_i and f_i are the emission coefficients of the ith unit generating, N the number of generators and P_i the active power of each generator, from the TPP.

2.3 Economical load dispatch constrains

2.3.1 Equality power balance constraint

The real power of each generator is limited by the lower and upper limits. The following equation is the equality restriction of power balance (Rizk-Allah, El-Sehiemy, & Wang, 2018).

$$\sum_{i=1}^{n} P_i - P^D - P^L \qquad (2)$$

where P_i is the output power of each i generator, P^D is the load demand and P^L are transmission losses, in other words, the total power generation has to meet the total demand P^D and the actual power losses in transmission lines P^L (Dewangan, Jain, & Huddar, 2015).

$$\sum_{i=1}^{n} P_i = P^D - P^L \qquad (3)$$

The calculation of power losses P^L involves the solution of the load flow problem, which has equality constraints in the active and reactive power on each bar as follows (Nwulu & Xia, 2015):

$$P^L = \sum_{i=1}^{n} B_i P_i^2 \qquad (4)$$

A simplification is applied to model the transmission losses, setting them as a function of the generator output through Kron's loss coefficient derivatives of the Kron formula for losses (Huang et al., 2018).

$$P^L = \sum_{i=1}^{n} \sum_{j=1}^{n} P_i B_{ij} P_j + \sum_{i=1}^{n} B_{0i} P_i + B_{00} \qquad (5)$$

where B_{ij}, B_{0i} and B_{00} are the energy loss coefficients in the transmission network and n is the number of generators. A reasonable accuracy can be obtained when the actual operating conditions are close to the base case, where the B coefficients were obtained (Gitizadeh & Ghavidel, 2014).

2.3.2 Production Capacity Constraint

The power capacity total generated from each generator is restricted by the lower limit and by the upper limit, so the constrain is (De et al., 2018):

$$P_{min.i} \leq P_i \leq P_{max.i} \qquad (6)$$

where P_i is the output power of the i generator, $P_{min.i}$, is the minimal power of the i generator and $P_{max.i}$, the maximal power of the i generator.

2.3.3 Fuel Delivery Constraint

At each time interval, the amount of fuel supplied to all units must be less than or equal to the fuel supplied by the seller, i.e. the fuel delivered to each unit in each interval should be within its lower limit $F_{min,i}$ and its upper limit $F_{max,i}$ so that (Qu et al., 2018):

$$F_{min.i} \leq F_{im} \leq F_{max.i}, i \in N, m \in M, \qquad (7)$$

where $F_{i,m}$ is the fuel supplied to the engine i at the interval m, $F_{i,min}$ is the minimum amount of fuel supplied to i generator and $F_{max,i}$ is the maximum amount of fuel supplied to i generator.

2.3.4 Optimization problem

The multi-objective optimization problem is defined as follow:

$$Minimize(P) = [F1(P), F_2(P)] \qquad (8)$$

where $F_1(P)$, $F_2(P)$ are the objective functions to be minimized over the set of permissible decision vector P.

2.3.5 Incremental fuel cost method

The incremental fuel cost can be obtained from the following equation (Tiwari, Dave, & Dwivedi, 2017):

$$IC_i = \left(2.a_i.P_{gi} + b_i\right) \ \$/MWh \qquad (9)$$

where IC_i is the incremental fuel cost a_i are the values of the different points of the actual curve of the incremental cost and b_i are the values of the points on the approximated curve (linear) of incremental cost. P_{gi} is the total power generation. The curve of incremental fuel cost is show in the following Figure. 2:

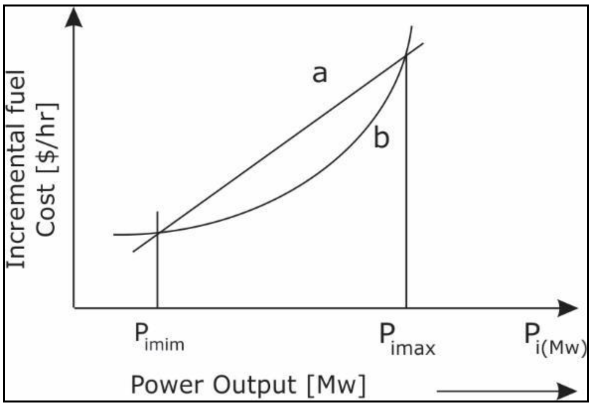

Fig.2: Incremental Cost Curve of Power Generator. Source:(Nascimento, Nunes, Rodríguez, Leite, & Junior, 2016)

2.4 Ant lion optimization

The Ant Lion Optimizer (ALO) is a algorithm inspired by nature (Mirjalili, 2015). The ALO algorithm mimics interaction between antlions and ants in the trap. To model such interactions, 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 modelling ants' movement as follows [28]:

$$X(t) = [0, cumsum\,(2r(t_1) - 1), cumsum(2r(t_2) - 1), \ldots, cumsum(2r(t_n) - 1)] \quad (10)$$

where cumsum calculates the cumulative sum, n is the maximum number of iteration, t shows the step of random walk (iteration in this study), and *r(t)* is a stochastic function defined as follows (Trivedi, Jangir, & Parmar, 2016):

$$r(t) = \begin{cases} 1 \ if \ rand > 0.5 \\ 0 \ if \ \ otherwise \end{cases} \qquad (11)$$

where t shows the step of random walk (iteration in this study) and *rand* is a random number generated with uniform distribution in the interval of [0, 1].

To keep the random walk in the boundaries of the search space and prevent the ants from overshooting, the random walks should be normalized using the following equation (Yao & Wang, 2017):

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

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

To simulate the trapping of ants the mathematical expression of the trapping of the ants to the ant lion's pits is given by following equations (Trivedi et al., 2016):

$$c_m^t = Ant - lion_n^t - c^t \qquad (13)$$

$$d_m^t = Ant - lion_n^t - d^t \qquad (14)$$

To construction of trap, the fittest ant lion is selected using the roulette wheel method.

To simulate the sliding ants towards ant lions, the boundaries of random walks should be reduced adaptively as follows (Mirjalili, 2015):

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

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

where $I = 10^w \frac{t}{s}$, t is current iteration, S is the maximum number of iterations and w is a constant whose value is given by (Raju, Saikia, & Sinha, 2016):

$$w = \begin{cases} 2 \ if \ t > 0.1S \\ 3 \ if \ t > 0.5S \\ 4 \ if \ t > 0.75S \\ 5 \ if \ t > 0.9S \\ 6 \ if \ t > 0.95S \end{cases} \qquad (17)$$

To catching the ants by ant lion and re-building the pit can be mathematically described as [28]:

$$Antlion_j^t = Ant_i^t, if \ f(Ant_i^t) > f\left(Antlion_j^t\right) \qquad (18)$$

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

Finally the last operator in ALO, that is elitism, calculated using roulette wheel as follows equation (Trivedi et al., 2016):

$$Ant_i^t = \frac{R_A^t + R_E^t}{2} \qquad (19)$$

where, R_A^t = the random walk nearby the ant lion chose by means of the roulette wheel at t^{th} iteration, R_E^t = the random walk nearby the elite at t^{th} iteration, Ant_i^t = the location of i^{th} ant at t^{th} iteration.

2.5 ALO applied to EELD

Initialize random walks on ants using Eq (10) and save generation scheduling of generating units as ant position using Eq (20) described below:

$$M_{Ant} = \begin{bmatrix} Ant_{1,1} & Ant_{1,2} & Ant_{1,3} & \ldots & Ant_{1,d} \\ Ant_{2,1} & Ant_{2,2} & Ant_{2,3} & \ldots & Ant_{2,d} \\ \ldots & \ldots & \ldots & \ldots & \ddots \\ Ant_{n,1} & \ldots & \ldots & \ldots & Ant_{n,d} \end{bmatrix}_{n \times d} \qquad (20)$$

where M_{Ant} is the matrix for saving the position of each ant, $Ant_{i,j}$ shows the value of the *j*th variable (dimension) of *i*th ant, n is the number of ants, and d is the number of variables.

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For evaluating each ant (i.e., generating units), the following objective functions described in Eq. (1) and Eq (2) are utilized during optimization and following matrix stores the fitness value of all ants:

$$M_{OA} = \begin{vmatrix} f([Ant_{1,1}, Ant_{1,2}, \cdots Ant_{1,d}]) \\ f([Ant_{2,1}, Ant_{2,2}, \cdots Ant_{2,d}]) \\ \vdots \\ f([Ant_{n,1}, Ant_{n,2}, \cdots, Ant_{n,d}]) \end{vmatrix} \quad (21)$$

where M_{OA} is the matrix for saving the fitness of each ant, $Ant_{i,j}$ shows the value of *j*th dimension of *i*th ant, *n* is the number of ants, and *f* is the objective function.

Save the optimal cost and generation scheduling using Eqs. (22) and (23) described below:

$$M_{OAL} = \begin{vmatrix} f([AL_{1,1}, AL_{1,2}, \cdots AL_{1,d}]) \\ f([AL_{2,1}, AL_{2,2}, \cdots AL_{2,d}]) \\ \vdots \\ f([AL_{n,1}, AL_{n,2}, \cdots, AL_{n,d}]) \end{vmatrix} \quad (23)$$

where M_{OAL} is the matrix for saving the fitness of each ant lion, $AL_{i,j}$ shows the *j*th dimension's value of *i*th ant lion, *n* is the number of ant lions, and *f* is the objective function.

This solution comprises the number of generations of the system that will be optimized, which results in minimization of cost and emissions described in Eq (8) by fulfilling all constraints described in Eq (3), Eq (6) and Eq (7).

Equation (8) are applied in the performance evaluation of the EELD until the optimum cost and emission is achieved. For inequality constraints, similar to any other techniques, when the solutions obtained for any iteration are out of boundaries, ALO chooses the boundaries values, while for equality constraint, when it is violated, the penalty factor of 1000 is implemented and embedded in the cost function as per Eq. (8). The algorithm will continue until the maximum iteration is met, and the optimum results are obtained.

III. SIMULATION TESTS AND RESUTS

The power plant selected for the case study consists of six generating units with a load demand of 900 MW where generation limits, fuel cost and emission coefficients for case study is take from Ref (Lee & Darwish, 2008; Manteaw & Odero, 2012).

The EELD problem simulated with the ALO algorithm, the systems of standard IEEE 30 bus systems have been taken into consideration (figure 3).

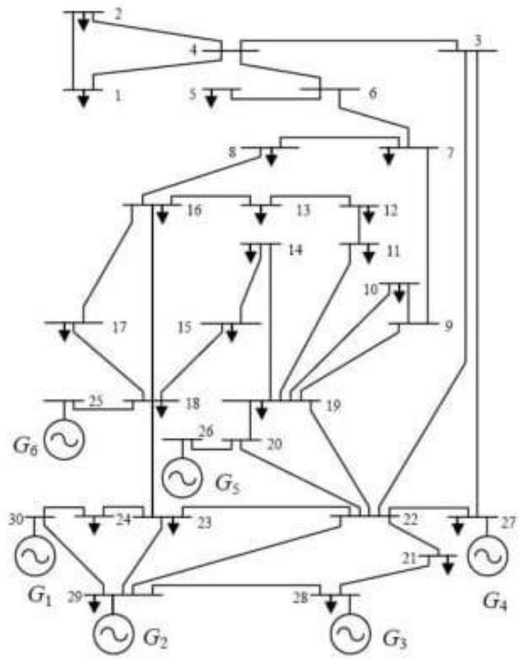

Fig.3: Diagram of IEEE 30-bus test system.
Source: (Lee & Darwish, 2008)

The data of IEEE 30 bus test system to apply in ALO optimizer is presented in table 1, table 2 and table 3.

Table.1: Characteristic data of the generators from the case study power plants.

Gen	c_i ($/MW^{2}h)	b_i ($/MWh)	a_i ($/h)	P_{min} (MW)	P_{max} (MW)
G1	0.15247	38.53973	756.79886	10	125
G2	0.10587	46.15916	451.32513	10	150
G3	0.02803	40.39655	1049.32513	40	250
G4	0.03546	38.30553	1243.5311	35	210
G5	0.02111	36.32782	1658.5696	130	325
G6	0.01799	38.27041	1376.27041	125	315

Source: (Manteaw & Odero, 2012)

Table.2: Coefficients of emission of the 6 generating unit.

Unit	d_i	e_i	f_i
G1	0.00419	0.32767	13.85932
G2	0.00419	0.32767	13.85932

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G3	0.00683	-0.54551	40.2669
G4	0.00683	-0.54551	40.2669
G5	0.00461	-0.51116	42.89553
G6	0.00461	-0.51116	42.89553

Source: (Manteaw & Odero, 2012)

Table.3: Loss coefficients (x10^{-6}).

2022	-286	-534	-565	-454	-103
-286	3243	16	-307	-422	-147
-535	16	2085	831	23	-270
-565	-307	831	1129	113	-295
-454	-422	23	113	460	-153
-103	-147	-270	-295	-153	898

Source: (Manteaw & Odero, 2012)

The results after running the simulation of the proposed ALO algorithm, are displayed in Tables 4.The simulation of the proposed ALO algorithm is tested in MATLAB R2016 to meet the demand of 900MW.

Table.4: Coefficients of emission of the 6 generating unit.

Generator	Power of each generator in Mw	Emission of each engine in Kg/h	Cost of each engine in $/h
G1	125	8238.41182	7956.60886
G2	92.7026704	3382.26922	5640.22656
G3	86.4365762	4403.87432	4750.48463
G4	151.819543	23857.7694	7876.38287
G5	240.571054	64104.5546	11619.7208
G6	229.179195	55417.1514	11071.9428
Total	925.709039	159404.0308	48915.36652

Source: Authors

The graphics with pareto front of costs versus emissions and the using all generators is presented in fig. 4.

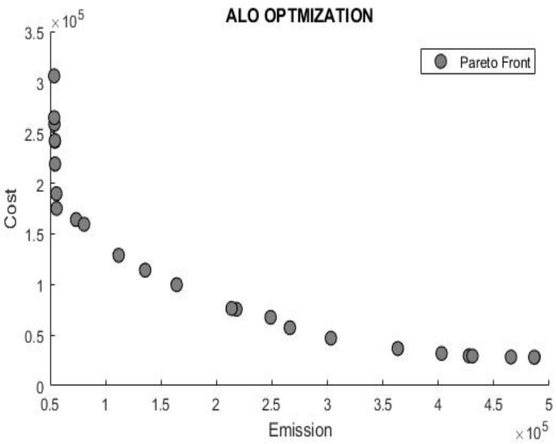

Fig.4: Pareto front of cost vs emission.

Source: Authors.

The graphics with power, emission and cost are presented in figure 5, 6 and 7 respectively.

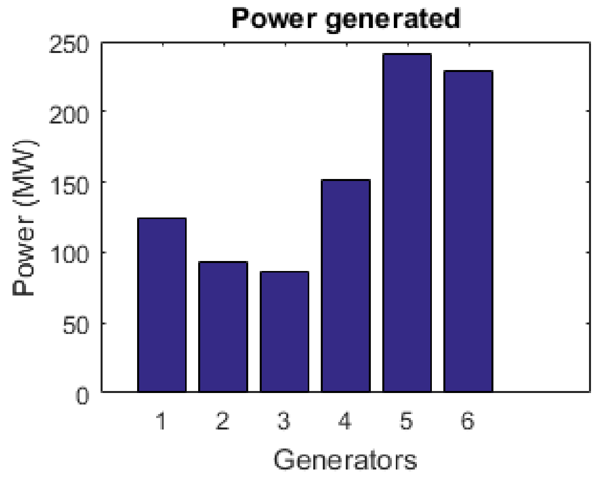

Fig.5: Power generated in each generator.

Source: Authors.

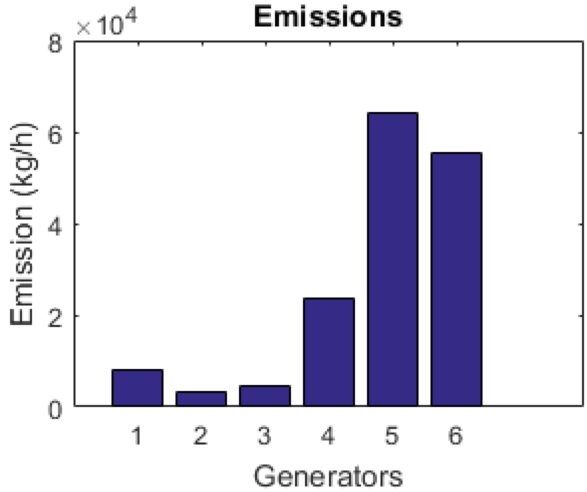

Fig.6: Emission in each generator.

Source: Authors.

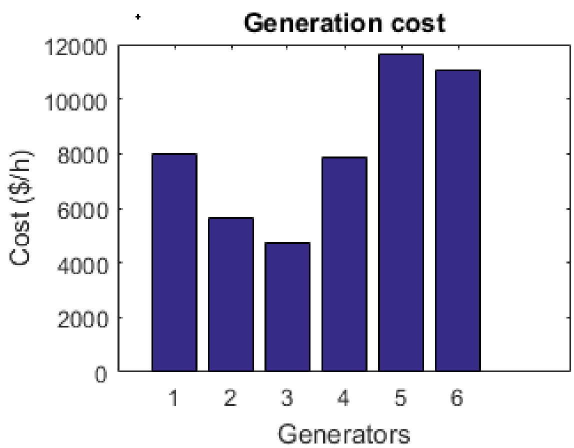

Fig.7: Cost of each generator.

Source: Authors.

IV. CONCLUSION

The ant lion optimizer is successfully applied to a 30 bus test system, to solve the EELD problem, so now it is possible to use these results to compare with other techniques that apply to this same IEEE bus test system system. This application can also help workers to operate more efficiently the generators in a power plant.

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