IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE)
e-ISSN: 2278-1676,p-ISSN: 2320-3331, Volume 12, Issue 6 Ver. I (Nov. – Dec. 2017), PP 87-92
www.iosrjournals.org

Ant Lion Optimization for Dynamic Economic Dispatch

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Abstract: *In this paper, Ant Lion Optimization (ALO) is presented to solve the dynamic economic dispatch (DED) problem considering valve-point effects, the ramp rate limits and transmission losses. The practical DED problems have non-smooth cost function with equality and inequality constraints, which make the problem of finding the global optimum difficult when using any mathematical approaches. The ALO is inspired by the hunting mechanism of ant lions in nature. It has fast convergence speed due to the use of roulette wheel selection technique. The effectiveness of the proposed algorithm has been verified on 10 unit generation system for a 24 h time interval. The results are compared with the results reported in the literature.*

Keywords - *Ant lion optimization, dynamic economic dispatch, non-smooth cost functions, ramp rate limits, valve-point effects*

Date of Submission: 15-11-2017 Date of acceptance: 25-11-2017

I. Introduction

Electrical power plays a pivotal role in the modern wold to satisfy various needs. It is therefore very important that the electrical power generated is trasmitted and distributed efficiently in order to satisfy the power requirement. The electrical power systems are interconnected in order to obtain the benefits of minimum generation costs, maximum reliability and best operational conditions, such as sharing of power reserve, improving the stability and operating on emergency situations. Thus, the optimization problem of the economic dispatch of electrical power system is relevant to accomplish requirements of quality and efficiency in power generation. Dynamic economic dispatch (DED) is one of important problems in modern power system operation and control, which is used to determine the optimal schedule of generating outputs on-line so as to meet the load demand at the minimum operating cost under various system and operating constraints over the entire dispatch periods. DED is an extension of the conventional economic dispatch (ED) problem that takes into consideration the limits on the ramp rate of generating units to maintain the life of generation equipment [1, 2].

Since the DED problem was introduced, several optimization techniques and procedures have been used for solving the DED problem with complex objective functions or constraints. There were a number of classical methods that have been applied to solve this problem such as gradient projection method, Lagrange relaxation, and linear programming [3-5]. Most of these methods are not applicable for non-smooth or non-convex cost functions. To overcome this problem, many stochastic optimization methods have been employed to solve the DED problem, such as genetic algorithm (GA) [6], simulated annealing (SA) [7], differential evolution (DE) [8, 9], particle swarm optimization (PSO) [10], hybrid EP and SQP [11], deterministically guided PSO [12], hybrid PSO and SQP [13], imperialist competitive algorithm (ICA) [14], and artificial immune system (AIS) [15]. Many of these techniques have proven their effectiveness in solving the DED problem without any or fewer restrictions on the shape of the cost function curves.

Recently, a new meta-heuristic search algorithm, called Ant Lion Optimizer (ALO), has been developed by Mirjalili in 2015 [16]. In this paper, ALO has been used to solve the DED problem considering ramp rate limits, valve-point effects and transmission loss. Feasibility of the proposed method has been demonstrated on 10-unit generation system. The results obtained with the proposed method were analyzed and compared with other optimization results reported in literature.

II. Problem Formulation

The objective of DED problem is to find the optimal schedule of output powers of online generating units with predicted power demands over a certain period of time to meet the power demand at minimum operating cost.

The fuel cost function of the generating unit is expressed as a quadratic function of real power generation. The objective function of the DED problem is

$$\min F_T = \sum_{t=1}^{T}\sum_{i=1}^{N} F_{i,t}(P_{i,t}) = \sum_{t=1}^{T}\sum_{i=1}^{N}\left(a_i P_{i,t}^2 + b_i P_{i,t} + c_i\right) \quad (1)$$
$$\text{for } i = 1,2,\cdots,N;\ t = 1,2,\ldots,T$$

where $F_{i,t}$ is the fuel cost of unit i at time interval t in \$/hr, a_i, b_i, and c_i are the cost coefficients of generating unit i, $P_{i,t}$ is the real power output of generating unit i at time period t in MW, and N is the number of generators. T is the total number of hours in the operating horizon.

The valve-point effects are taken into consideration in the DED problem by superimposing the basic quadratic fuel-cost characteristics with the rectified sinusoid component as follows:

$$\min F_T = \sum_{t=1}^{T}\sum_{i=1}^{N} F_{i,t}(P_{i,t}) = \sum_{t=1}^{T}\sum_{i=1}^{N}\left(a_i P_{i,t}^2 + b_i P_{i,t} + c_i + \left|e_i \times \sin\left(f_i \times \left(P_{i,\min} - P_{i,t}\right)\right)\right|\right) \quad (2)$$

where F_T is total fuel cost of generation in (\$/hr) including valve point loading, e_i, f_i are fuel cost coefficients of unit i reflecting valve-point effects.

The fuel cost is minimized subjected to the following constraints:

2.1. Active Power Balance Equation

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

$$\sum_{i=1}^{N} P_{i,t} = P_{D,t} + P_{L,t} \quad (3)$$

where $P_{D,t}$ and $P_{L,t}$ are the load demand and transmission loss in MW at time interval t, respectively.

The transmission loss $P_{L,t}$ can be expressed by using ***B*** matrix technique and is defined by (4) as,

$$P_{L,t} = \sum_{i=1}^{n}\sum_{j=1}^{n} P_{i,t} B_{ij} P_{j,t} \quad (4)$$

where B_{ij} is coefficient of transmission loss.

2.2. Minimum and Maximum Power Limits

Generation output of each generator should lie between minimum and maximum limits. The corresponding inequality constraint for each generator is

$$P_{i,\min} \le P_{i,t} \le P_{i,\max} \quad (5)$$

where $P_{i,\,min}$ and $P_{i,\,max}$ are the minimum and maximum real power output of unit i in MW, respectively.

2.3. Ramp Rate Limits

The actual operating ranges of all on-line units are restricted by their corresponding ramp rate limits. The ramp-up and ramp-down constraints can be written as (6) and (7), respectively.

$$P_{i,t} - P_{i,t-1} \le UR_i \quad (6)$$

$$P_{i,t-1} - P_{i,t} \le DR_i \quad (7)$$

where $P_{i,t}$ and $P_{i,t-1}$ are the present and previous power outputs, respectively. UR_i and DR_i are the ramp-up and ramp-down limits of unit i (in units of MW/time period).

To consider the ramp rate limits and power output limits constraints at the same time, therefore, equations (5), (6) and (7) can be rewritten as follows:

$$\max\{P_{i,\min}, P_{i,t-1} - DR_i\} \le P_{i,t} \le \min\{P_{i,\max}, P_{i,t-1} + UR_i\} \quad (8)$$

III. Ant Lion Optimization (ALO)

Ant Lion Optimizer (ALO) is a novel nature-inspired algorithm presented by Mirjalili in 2015 [16]. The ALO emulates the hunting mechanism of ant lions in nature. An ant lion larva digs a cone shaped pit in sand by moving along a circular path and throwing out sands with its massive jaw. After digging the trap, the larva hides underneath the bottom of the cone and waits for insects to be trapped in the pit. The edge of the cone is sharp enough for insects to fall to the bottom of the trap easily. Once the ant lion realizes that a prey is in the trap, it tries to catch it. Then, it is pulled under the soil and consumed. After consuming the prey, ant lions throw the leftovers outside the pit and prepare 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. To model such interactions, ants are required to move over the search space and ant lions 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 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 location 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} matrix to save the position of each ant

ant_{ij} value of *j*-th variable (dimension) of *i*-th ant

n number of ants

d number of variables

During optimization, matrix M_{ant} will save the position of all ants (variables of all solutions). To keep the random walks inside the search space, they are normalized 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 Minimum random walk of *i*-th variable

d_i Maximum random walk of *i*-th variable

c_i^t Minimum of *i*-th variable at *t*-th iteration

d_i^t Maximum of *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 ant lion's pits.

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

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

where,

c^t Minimum of all variables at *t*-th iteration

d^t Maximum of all variables at *t*-th iteration

c_i^t Minimum of all variables of *i*-th ant

d_i^t Maximum of all variables oft *i*-th ant

$Antlion_j^t$ Position of selected *j*-th ant lion 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 (15) and (16),

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

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

where,

I	ratio
c^t	Minimum vector of all variables at *t*-th iteration
d^t	Maximum vector 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.

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. Ant lion pulls 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:

$$Antlion_j^t = Ant_i^t,\ if \quad f(Ant_i^t) > f(Antlion_j^t) \tag{17}$$

where,

t	current iteration
$Antlion_j^t$	Position of selected *j*-th ant lion at *t*-th iteration
Ant_i^t	Position of *i*-th ant for *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:

$$Ant_i^t = \frac{R_A^t + R_E^t}{2} \tag{18}$$

where,

R_A^t	Random walk around ant lion selected by roulette wheel at *t*-th iteration
R_E^t	Random walk around the elite at *t*-th iteration
Ant_i^t	Position of *i*-th ant for t-th iteration

The pseudo code of the ALO algorithm is shown in Table I.

Table I Pseudo-code of ALO

```
Ant Lion Optimization (ALO)
Initialize the first population of ant and ant lions randomly
Calculate the fitness of ants and ant lions
Find the best ant lions and assume it as the elite (determined optimum)
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 DED problem was solved using the proposed ALO and its performance is compared with other methods reported in recent literature. The proposed technique has been applied to 10 unit generation system. The algorithm was implemented in MATLAB 7.1 on a Pentium IV personal Computer with 3.6 GHz speed processor and 2 GB RAM. The dispatch horizon is selected as one day with 24 dispatch periods of each one hour.

In this case, generator capacity limits, ramp rate constraints, valve-point effects and transmission losses are considered. The data for this system has been adopted from [17]. The load demand for each time interval over the scheduling period is given in Table II. The optimal dispatch of real power for the given scheduling horizon using proposed ALO is given in Table III. The best solution obtained through the proposed method is compared to those reported in the recent literature are shown in Table IV. The best total generation cost obtained using proposed method is $ 2469756.8673 and the computation time taken by the algorithm is 40.12 s. It clear from the table that the proposed method produces much better results compared to recently reported different method for solving DED problem.

Table II Load demand for 24 hours (10-unit system)

Time (h)	Load (MW)	Time (h)	Load (MW)	Time (h)	Load (MW)	Time (h)	Load (MW)
1	1036	7	1702	13	2072	19	1776
2	1110	8	1776	14	1924	20	2072
3	1258	9	1924	15	1776	21	1924
4	1406	10	2072	16	1554	22	1628
5	1480	11	2146	17	1480	23	1332
6	1628	12	2220	18	1628	24	1184

Table III Best scheduling of 10-unit system using ALO

Hour	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
1	150.0000	135.0000	143.4172	120.0859	128.7120	113.0967	93.4095	113.8040	45.2993	12.6535
2	150.0000	135.0000	86.3181	151.5816	182.9570	141.4506	120.0479	97.1180	50.1347	17.6682
3	150.0000	135.0012	182.0039	231.2239	238.4647	159.9735	30.6992	89.9172	22.1852	47.4028
4	150.0000	135.0000	258.6434	232.8210	202.5981	125.3488	129.6088	119.9996	59.4680	28.1817
5	150.0000	135.0000	248.1779	269.8254	227.8701	141.1456	129.9884	104.0308	72.1584	41.3396
6	150.0000	136.6016	340.0000	300.0000	243.0000	160.0000	130.0000	120.0000	44.5309	52.0281
7	150.0000	176.9469	340.0000	300.0000	243.0000	160.0000	129.9988	120.0000	80.0000	55.0000
8	181.9599	224.4393	340.0000	300.0000	243.0000	160.0000	130.0000	120.0000	80.0000	55.0000
9	247.7186	318.8484	340.0000	300.0000	243.0000	160.0000	130.0000	120.0000	80.0000	55.0000
10	307.3116	421.1835	340.0000	300.0000	243.0000	160.0000	130.0000	120.0000	80.0000	55.0000
11	350.0713	460.0000	340.0000	300.0000	243.0000	160.0000	130.0000	120.0000	80.0000	55.0000
12	432.0750	460.0000	340.0000	300.0000	243.0000	160.0000	130.0000	120.0000	80.0000	55.0000
13	313.7773	414.6898	340.0000	300.0000	243.0000	160.0000	130.0000	120.0000	80.0000	55.0000
14	235.3788	331.2284	340.0000	300.0000	243.0000	160.0000	130.0000	120.0000	80.0000	55.0000
15	166.0252	240.4079	340.0000	300.0000	243.0000	160.0000	130.0000	120.0000	80.0000	55.0000
16	150.0001	135.0002	302.8820	276.8473	242.9398	153.2994	106.3999	119.6304	79.2741	31.4766
17	150.0000	135.0000	285.2655	265.3667	242.1843	115.8150	128.9368	115.1527	66.0051	16.0445
18	150.0000	135.0001	329.2986	285.8655	242.9998	159.9613	129.3058	117.1195	76.2396	50.2828
19	170.6620	235.7575	340.0000	300.0000	243.0000	160.0000	130.0000	120.0000	80.0000	55.0000
20	309.1588	419.3277	340.0000	300.0000	243.0000	160.0000	130.0000	120.0000	80.0000	55.0000
21	226.5207	340.1289	340.0000	300.0000	243.0000	160.0000	130.0000	120.0000	80.0000	55.0000
22	150.0000	135.0000	332.0047	295.1697	242.9999	156.2445	113.0322	119.6351	78.3548	53.7599
23	150.0000	135.0000	205.8268	172.4420	185.6019	159.5441	129.9458	119.99996	60.4916	44.9519
24	150.0000	135.0000	137.6292	110.4841	210.2743	149.0142	129.9567	64.2043	75.3516	47.5307
Total generation cost ($) = 2469756.8673; Total power loss (MW) = 1316.6626										

Table IV Comparison of cost and computing time

Method	Generation cost ($)	Computing time (s)
GA [15]	2,596,847.38	71.24
PSO [15]	2,5801,48.25	69.88
MBFA [15]	2,544,523.21	54.77
AIS [15]	2,500,684.32	49.82
ALO	2,469,756.87	40.12

V. Conclusion

In this paper, ALO algorithm has been successfully applied for solving the DED problem. The effectiveness of this algorithm is demonstrated for 10-unit generation system. The obtained results from the test systems have indicated that the proposed technique has a much better performance than other optimization methods reported in the literature. In addition, the results substantiate the robustness, precise convergence and efficiency of this optimization algorithm. The main advantage of ALO algorithm is a good ability for finding the solution. From the results obtained it can be concluded that ALO is a competitive technique for solving complex non-smooth optimization problems in power system operation.

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Hardiansyah Ant Lion Optimization for Dynamic Economic Dispatch.” IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE), vol. 12, no. 6, 2017, pp. 87-92.