ECONOMIC LOAD DISPATCH PROBLEM FORMULATION OPTIMIZATION METHODOLOGY USING OPPOSITION-BASED ALO

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Abstract - *In this paper, a new modified ALO i.e. opposition-based ALO (OALO) is introduced to solve the economic dispatch problem considering practical constraints like vale-point effects, power balance and generator limits are presented. The solution is extended to multiple fuels too. Five test cases are considered i.e. thirteen generator system with and without valve-point effects, fifteen generator systems with and without valve-point effects and a ten generator multiple fuels system. To validate the superior performance of the proposed OALO, the results obtained from OALO are compared with results obtained from ALO and kinetic-gas molecules optimization (KGMO).*

***Key Words*: Economic load dispatch; equality and inequality constraints; valve-point loading effects; ant lion optimization, opposition-based learning.**

1. INTRODUCTION

In modern power networks, the economic load dispatch (ELD) is considered as a problem when two or more than two power generating units together generate the electric power which is more in comparison to required generation demand. Several efforts in the past are carried out to resolve the problem of allocating the schedule generation of each generating units in a plant. Practically, the conventional power plants are situated far from the load centres. This results in the variation of the fuel costs of generators. Under normal operating conditions, it is required that the total generation of the plant should exceed the total power demand and incurred losses. In order to tackle this problem, various methods of dispatch scheduling are used in practice. Owing to the fast-growing power demand, the modern power systems are getting interconnected with each other. In this interconnected power system, the vital task is to schedule the total load demand among available generating units in such a way that the total cost incurred is minimum after all system constraints satisfied. The above stated process is considered as ELD problem in power.

Ant-lion optimization (ALO) is a population based optimization algorithm introduced by Mirjalili in 2015. It based on the behaviour of ant-lions in the environment. An opposition based learning is introduced by Tizhoosh in 2005. In this thesis, a new modified ALO i.e. opposition-based ALO (OALO) is introduced to solve the economic dispatch problem considering practical constraints like vale-point effects, power balance and generator limits are presented. The solution is extended to multiple fuels too. Five test cases are considered i.e. thirteen generator system with and without valve-point effects, fifteen generator systems with and without valve-point effects and a ten generator multiple fuels system. To validate the superior performance of the proposed OALO, the results obtained form OALO are compared with results obtained from ALO and kinetic-gas molecules optimization (KGMO).

2. Problem Formulation

In practical cases, the formulation of fuel cost of generators is taken in the form of quadratic function of generated output real power. However, the cost characteristic can be classified on the basis of smooth and non-smooth nature as smooth cost characteristic and non-smooth characteristic curve.

2.1 ELD with smooth cost function: It represents the simplest cost function. It can be expressed as a single quadratic function

$$F_i\left(P_i\right) = a_i P_i^2 + b_i P_i + c_i$$

where, a_i, b_i and c_i are the cost coefficients of ith generating unit. P_i is the generated power of the ith unit.

2.2 ELD with non-smooth cost function: It includes multiple non-differentiable points in order to represent the valve-points loading effects that are present in EDP. Valve-point loading effect is a phenomenon that occurs in power plants that usually have multiple valves to control the power output of the units. When steam admission valves are first opened in thermal units, a sudden increase in losses is observed which leads to ripples in the cost function curve. It can be expressed as a quadratic and a sinusoidal function:

$$F_i\left(P_i\right) = a_i P_i^2 + b_i P_i + c_i + \left| e_i \sin\left(f_i \left(P_i^{\min} - P_i \right) \right) \right|$$

where, e_i and f_i are the fuel cost coefficients of the ith unit. $P_i^{\min}$ is the minimum generation limit of the ith unit. The total fuel cost (in $/hr) of the plant is given as

$$TC = \sum_{i=1}^{N} F_i\left(P_i\right)$$

where, TC is the total fuel cost of the plant and N is the total number of generating units in the plant.

2.3 System constraints

As it is mentioned before, the schedule has to minimize the total production cost and involves the satisfaction of both equality and inequality constraints.

2.3.1 Power Balance Constraint: The power generated has to be equal to the power demandrequired. It is defined as:

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

where, P_D is the total load demand.

2.3.2 Operating Limit Constraints: Thermal units have physical limits about the minimum and maximum power that can generate:

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

where, $P_i^{\min}$ and $P_i^{\max}$ are the minimum and maximum generating limits of the ith generating unit.

The operating limit constraints are tackled by assigning the generation to a unit equal to its minimum generation if its generation is less than the minimum value and equal to maximum generation if it exceeds its maximum value. The following pseudo code is used:

if $P_i > P_i^{\max}$

$P_i = P_i^{\max}$;

else if $P_i < P_i^{\min}$

$P_i = P_i^{\min}$

end

To satisfy the power balance constraint, a penalty factor method is used. A penalty of high value is added to the cost function when power balance constraint is violated. A pseudo code defining the above statement is given below:

if $\sum_{i=1}^{N} P_i < P_D$

$penalty$ = 10^6;

else

$penalty$ = 0;

end

Now, the modified objective function is converted to

$$TC = \sum_{i=1}^{N} F_i\left(P_i\right) + penalty$$

subject to constraint defined in (4) and (5).

3. Optimization Techniques

3.1 Ant Lion optimization (ALO)

The ALO algorithm is proposed by Mirjalili et al. in 2015 [16]. It imitates the behaviour of antlions and ants in the trap. The behaviour is mathematically modelled on the basis of random walk of ants in the entire search space and hunting of the ants by the antlions by making traps to get fitter. The ants randomly move in the search space in order to locate food, therefore, their walk is modelled as a random walk defined as:

$$X(r) = \left[0, cumsum\left(2s(r_1)-1\right), cumsum\left(2s(r_1)-1\right), \cdots cumsum\left(2s(r_G)-1\right)\right]$$

where, $cumsum$ is the cumulative sum, G is the maximum number of generation, r is the current generation, and $s(r)$ is a stochastic function calculated as follows:

$$s(r) = \begin{cases} 1 & \text{if} \quad rand(\ ) > 0.5 \\ 0 & \text{otherwise} \end{cases} \quad (4)$$

where, r is the current iteration and $rand(\ )$ is any random number in the interval [0,1].

The random initializations of ants and antlions within the search space is carried out. The positions of ants and antlions are stored in following matrices:

$$P_A = \begin{bmatrix} P_{1,1} & P_{1,2} & \cdots & P_{1,D} \\ P_{2,1} & P_{2,2} & \cdots & P_{2,D} \\ \vdots & \vdots & \cdots & \vdots \\ P_{N,1} & P_{N,2} & \cdots & P_{N,D} \end{bmatrix} \quad (5)$$

and

$$Q_{AL} = \begin{bmatrix} Q_{1,1} & Q_{1,2} & \cdots & Q_{1,D} \\ Q_{2,1} & Q_{2,2} & \cdots & Q_{2,D} \\ \vdots & \vdots & \cdots & \vdots \\ Q_{N,1} & Q_{N,2} & \cdots & Q_{N,D} \end{bmatrix}$$

where, P_A and Q_{AL} is the population of ants and antlions, respectively. N is the population size and D is the dimension of the problem.

3.1.1 Random walks of the ants

The ants in **Error! Reference source not found.** update their positions at every iteration by randomly walking in the search space according to:

$$X_i^r = \frac{\left(X_i^r - e_i\right)\times\left(f_i - g_i^r\right)}{\left(h_i^r - e_i\right)} + g_i^r$$

where, e_i and f_i are the minimum and maximum of random walks of ith variable, respectively.

3.1.2 Trappings of ants in the pits of antlions

It is observed that the random walks of the ants are affected by the presence of pits of antlions. This situation is mathematically expressed as:

$$g_i^r = Q_j^r + g^r$$

$$h_i^r = Q_j^r + h^r \quad (6)$$

where, g^r is minimum of all variables at rth iteration and h^r is vector of maximum of all variables at rth iteration.

3.1.3. Sliding of ants towards antlions

When an ant is trapped in the pit then, it is required that it should not escape from the trap. In order to achieve the same, antlions shoot out sands outwards towards the centre of the pit. The phenomenon is mathematically modelled as:

$$g^r = \frac{g^r}{K}$$

$$h^r = \frac{h^r}{K} \quad (7)$$

where, K is a ratio which is equal to $K = 10^{\alpha}$ and r is the current iteration. The value of α is defined in the following manner:

$$\alpha = \begin{cases} 2 & \text{when} \quad r > 0.1R \\ 3 & \text{when} \quad r > 0.5R \\ 4 & \text{when} \quad r > 0.75R \\ 5 & \text{when} \quad r > 0.9R \\ 6 & \text{when} \quad r > 0.95R \end{cases}$$

where, R is the maximum iteration.

3.1.4 Elitism

Elitism is an important aspect of any optimization technique. The best antlion obtained so far is saved and is used to direct the random walks of the ants at every iteration. It is further assumed that an ant randomly walks around a roulette wheel selected antlion and the elite antlion simultaneously. This phenomenon is expressed as:

$$P_i^r = \frac{w_A^r + w_E^r}{2} \quad (16)$$

where, w_A^r is the random walk of the ant around roulette wheel selected antlion at rth iteration and w_E^r is the random walk of the ant around elite antlion at rth iteration. The structure of ALO algorithm is organized in the manner it is defined above. The flowchart of the algorithm is shown below.

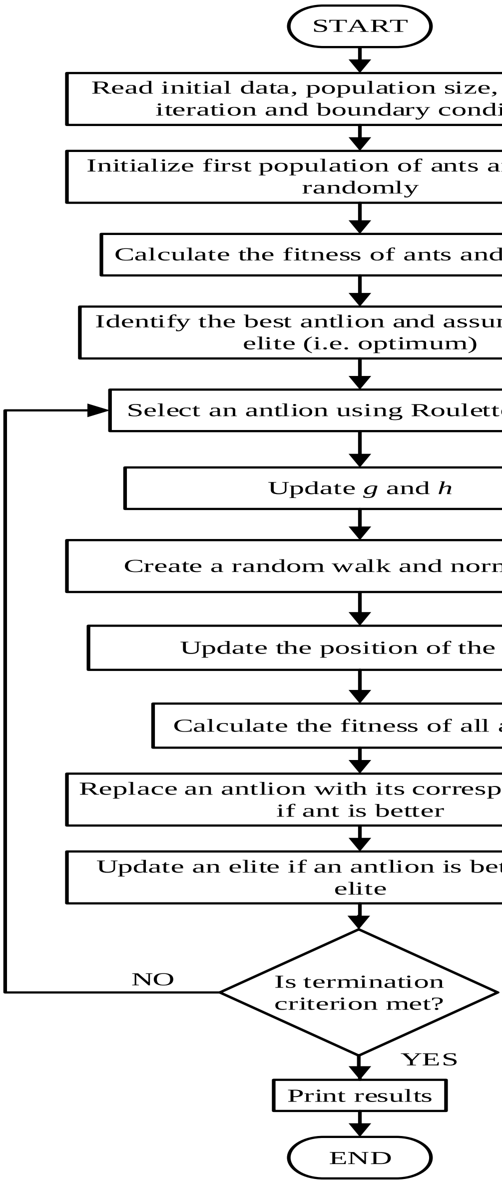

Fig. 1. Flowchart of ALO algorithm

3.2 Opposition-based learning

Let $x \in \Re$ be a real number defined on a certain interval: $x \in [a,b]$. The opposite number $\tilde{x}$ is defined as follows:

$$\tilde{x} = a + b - x$$

For $a = 0$ and $b = 1$ it is received

$$\tilde{x} = 1 - x$$

Analogously, the opposite number in a multidimensional case can be defined. Definition – Let $P(x_1, x_2, \ldots, x_n)$ be a point in a n-dimensional coordinate system with $x_1, \ldots, x_n \in \Re$ and $x_i \in [a_i, b_i]$. The opposite point $\tilde{P}$ is completely defined by its coordinates $\tilde{x}_1, \ldots, \tilde{x}_n$ where

$$\tilde{x}_i = a_i + b_i - x_i \quad i = 1, \ldots, n \quad (19)$$

The opposition scheme for learning can now be concretized: (20)

3.3 Opposition ant lion algorithm (OALO)

In opposition-based ALO, the opposite population of the random initial population of ants and ant-lions defined in (9) and (10), respectively, are found out using (21). This opposite population undergoes the process of update phase by ALO algorithm and the rest of the process remains same as ALO algorithm.

4. Simulation Results and discussion

In this work, a modified opposition-based ant-lion optimization (OALO) algorithm is proposed to solve a non-convex economic load dispatch (ELD) problem. The following section discusses the different test cases considered.

Case 1: A thirteen generator system

An IEEE standard thirteen generator system is considered. In this system, the total load demand is 850 MW. The smooth and non-smooth cost characteristics are considered for the simulation. Table 1 shows the economic load dispatch for the system without considering transmission losses and the valve-point loading effects. The results obtained from OALO are compared with ALO and KGMO. From the table, it can be clearly seen that the minimum total cost of generation i.e. 17952.5289 $/h is obtained with OALO while ALO is incurring 17970.7139 $/h and KGMO is incurring 17995.1048 $/h. This suggests that OALO algorithm is more superior to ALO and KGMO in obtaining optimal power dispatch. Fig. 2 shows the convergence characteristics of the algorithms for the taken system. From the figure, it can be inferred that OALO converges to minimum value faster in comparison to ALO and KGMO.

Table 1 Economic load dispatch for Case 1 without valve-point loading effects

Generating Units	Economic load dispatch in MW		
	KGMO	ALO	OALO
Unit 1	389.7352	487.4054	496.8921
Unit 2	226.1426	231.8853	291.2307
Unit 3	210.5273	326.0806	203.7589
Unit 4	106.0414	83.1948	103.1291
Unit 5	151.0895	169.2991	85.6689
Unit 6	116.6581	60.2896	121.4557
Unit 7	137.6128	69.1255	67.3890
Unit 8	101.9196	63.2586	152.2209
Unit 9	92.4025	106.9296	83.4250
Unit 10	52.4271	51.0161	40.1523
Unit 11	77.6713	41.5070	41.7720
Unit 12	63.9440	55.0083	57.9056
Unit 13	73.8336	55.0000	55.0001
Total cost of generation ($/h)	17995.1048	17970.7139	**17952.5289**

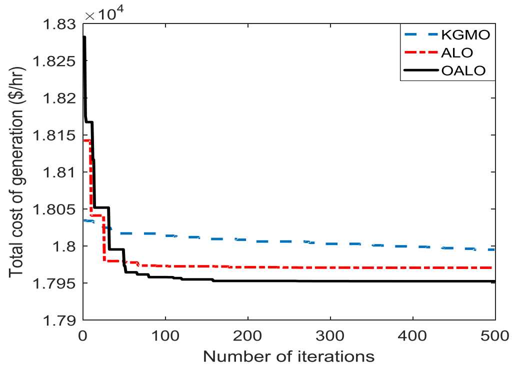

Fig. 2 Convergence characteristics for Case 1 without valve-point loading effects

When the non-smooth nature of the cost is considered, the total cost of generation is ought to increase. Table 2 shows the comparative results obtained for economic load dispatch for the system considering the valve-point loading effects with transmission losses neglected. From the table, it can be observed that the minimum total cost of generation i.e. 18040.7854 $/h is obtained with OALO while ALO is incurring 18341.1092 $/h and KGMO is incurring 18659.9433 $/h. This suggests that OALO algorithm is more superior to ALO and KGMO in obtaining economic load dispatch. Also, in this case, it can be seen that the total cost of generation is increased with the inclusion of valve-point loading effects in the problem. Fig. 3 shows the convergence characteristics of the algorithms for the studied system. From the figure, it can be concluded that OALO algorithm converges to minimum value faster in comparison to ALO and KGMO which again confirms the superior performance of the proposed algorithm over other.

Table 2 Economic load dispatch for Case 1 with valve-point loading effects

Generating Units	Economic load dispatch in MW		
	KGMO	ALO	OALO
Unit 1	463.9770	415.8570	677.8659
Unit 2	56.4041	24.7587	228.2891
Unit 3	217.0116	2.5431	340.4141
Unit 4	160.6301	69.0261	60.0000
Unit 5	132.0983	179.2309	60.0000
Unit 6	130.8615	178.1837	60.2441
Unit 7	71.0258	179.2309	60.0000
Unit 8	118.4416	176.6876	60.0000
Unit 9	103.2844	179.7292	60.0000
Unit 10	78.5948	42.8436	40.0000
Unit 11	80.7750	119.5888	40.1865
Unit 12	90.8053	118.8410	58.5526
Unit 13	97.1488	119.5522	55.0001
Total cost of generation ($/h)	18659.9433	18341.1092	**18040.7854**

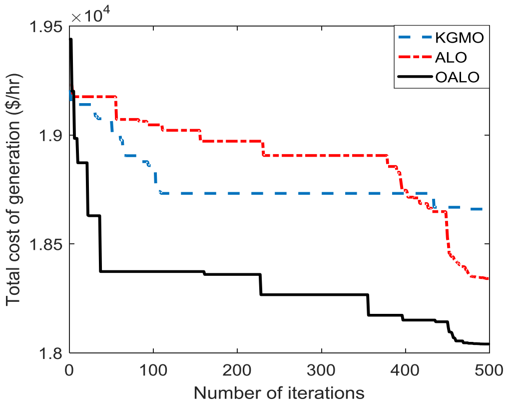

Fig. 3 Convergence characteristics for Case 1 with valve-point loading effects

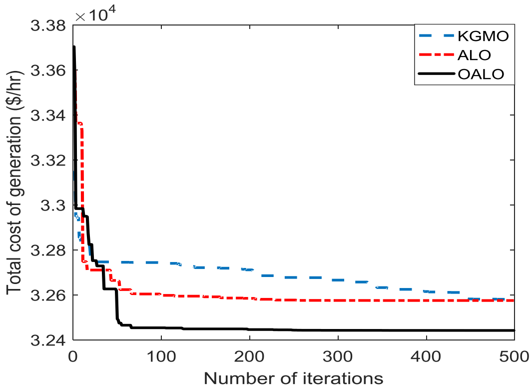

Fig. 4 Convergence characteristics for Case 2 without valve-point loading effects

Case 2: A fifteen generator system

An IEEE standard fifteen generator system is considered. In this system, the total load demand is 1263 MW. The smooth and non-smooth cost characteristics are considered here for the simulation. Table 3 shows the economic load dispatch for the system without considering transmission losses and the valve-point loading effects. The results obtained from OALO are compared with ALO and KGMO for this system also. From the table, it can be observed that the minimum total cost of generation i.e. 32441.7972 $/h is obtained with proposed OALO while ALO is incurring 32574.8610 $/h and KGMO is incurring 32580.4055 $/h. This suggests that OALO algorithm is more superior to ALO and KGMO in obtaining economic load dispatch. Fig. 4 shows the convergence characteristics of the algorithms for the taken system. From the figure, it can be seen that OALO converges to minimum value faster in comparison to ALO and KGMO.

Table 3 Economic load dispatch for Case 2 without valve-point loading effects

Generating Units	Economic load dispatch in MW		
	KGMO	ALO	OALO
Unit 1	310.6716	433.1855	443.4224
Unit 2	409.5060	286.6795	223.3486
Unit 3	103.8854	128.7015	129.9983
Unit 4	96.2118	98.1359	129.0322
Unit 5	384.7923	334.2439	379.3932
Unit 6	381.2707	368.1332	452.6513
Unit 7	441.5485	448.2451	460.0656
Unit 8	194.4216	84.1165	61.8769
Unit 9	61.8015	144.1429	29.1959
Unit 10	76.1219	122.5448	81.6062
Unit 11	49.5606	37.5654	66.2245
Unit 12	50.4942	55.0680	70.0758
Unit 13	28.6708	25.0000	39.3023
Unit 14	17.9459	35.4564	19.3539
Unit 15	23.0983	28.7814	44.4529
Total cost of generation ($/h)	32580.4055	32574.8610	**32441.7972**

When the non-smooth nature of the cost is considered, the total cost of generation is ought to increase. Table 4 shows the comparative results obtained for economic load dispatch for the system considering the valve-point loading effects with transmission losses neglected. From the table, it can be inferred that the minimum total cost of generation i.e. 32582.2966 $/h is obtained with proposed OALO while ALO is incurring 32882.3377 $/h and KGMO is incurring 33155.7869 $/h. This suggests that OALO algorithm is more superior to ALO and KGMO in obtaining economic load dispatch. Also, in this case, it can be seen that the total cost of generation is increased with the inclusion of valve-point loading effects in the problem. Fig. 5 shows the convergence characteristics of the algorithms for the studied system. From the figure, it can be observed that proposed OALO algorithm converges to minimum value faster in comparison to ALO and KGMO which again confirms the superior performance of the proposed algorithm over other.

Table 4 Economic load dispatch for Case 2 with valve-point loading effects

Generating Units	Economic load dispatch in MW		
	KGMO	ALO	OALO
Unit 1	412.0364	428.9251	150.0000
Unit 2	389.8862	150.0000	447.8023
Unit 3	82.6147	123.7900	129.0380
Unit 4	90.4408	113.9660	116.3954
Unit 5	299.1055	399.1951	448.9994
Unit 6	258.7727	421.0762	445.0205
Unit 7	386.1718	458.7326	450.0781
Unit 8	291.6361	236.0859	60.9531
Unit 9	109.4334	28.5977	78.2681
Unit 10	59.8081	27.1968	98.0346
Unit 11	56.1681	35.6399	78.2289
Unit 12	62.8223	42.1848	55.2386
Unit 13	66.8436	77.3727	27.8866
Unit 14	38.3991	43.5048	15.2886
Unit 15	26.0382	46.1868	28.8593
Total cost of generation ($/h)	33155.7869	32882.3377	**32582.2966**

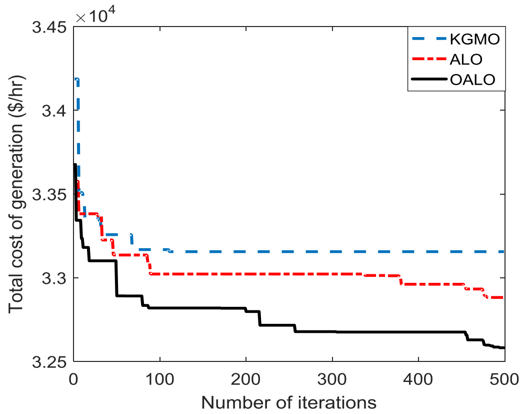

Fig. 5 Convergence characteristics for Case 2 with valve-point loading effects

Case 3: A ten generator system with multiple fuels

An IEEE standard thirteen generator system is considered. In this system, the total load demand is 2700 MW. The smooth cost characteristics is considered for the simulation for this system. Table 5 lists the economic load dispatch for the system without considering transmission losses and the valve-point loading effects. The results obtained from proposed OALO are compared with ALO and KGMO in this case also. From this table, it can be clearly observed that the minimum total cost of generation i.e. 626.4933 $/h is obtained with OALO algorithm while ALO is incurring 636.0982 $/h and KGMO is incurring 644.3833 $/h. This suggests that OALO is more superior to ALO and KGMO in obtaining economic load dispatch. Fig. 6 shows the convergence characteristics of the algorithms for the taken system. From the figure, it can be inferred that the convergence rate of OALO is higher in comparison to ALO and KGMO.

Table 5 Economic load dispatch for Case 3 without valve-point loading effects

Generating Units	KGMO		ALO		OALO	
	Optimal dispatch in MW	Fuel type	Optimal dispatch in MW	Fuel type	Optimal dispatch in MW	Fuel type
Unit 1	219.7860	2	231.9615	2	225.5315	2
Unit 2	208.9794	1	214.9138	1	212.1229	1
Unit 3	288.3231	1	403.8391	2	298.4354	1
Unit 4	236.6130	3	234.2951	3	242.0484	3
Unit 5	292.2532	1	272.3652	1	300.7350	1
Unit 6	199.1474	1	238.6956	3	238.2735	3
Unit 7	298.3776	1	280.7719	1	306.4549	1
Unit 8	235.5777	3	240.0465	3	244.8168	3
Unit 9	342.9360	1	333.7030	1	350.7254	1
Unit 10	378.0630	3	249.4082	1	280.8562	1
Total cost of generation ($/h)	644.3833		636.0982		**626.4933**	

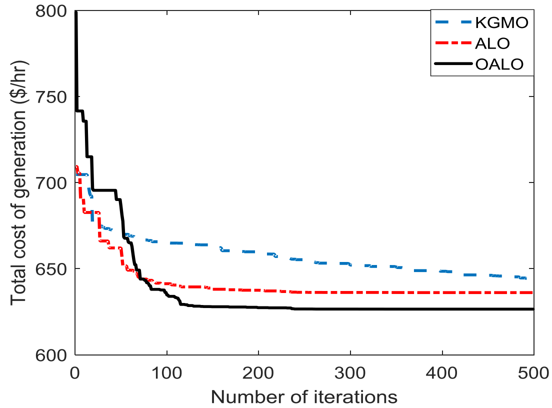

Fig. 6 Convergence characteristics for Case 3 without valve-point loading effects

From the above results and discussion, it can be easily be inferred that the modification done in the proposed algorithm by oppositional-based has a dominant effect on the performance of the algorithm. The modification enhances the performance of the algorithm as the solution obtained after the initialization is nearer to optimal solution. From the results, it is observed that **OALO** algorithm is always performing better than ALO and far better than KGMO

5. CONCLUSION

In this work, a non-convex economic load dispatch (ELD) problem is solved with a novel proposed algorithm. The proposed algorithm is a modified version of ant-lion optimization (ALO). The proposed modification in done by introducing oppositional-based learning to the random initialized population. This modification has a great impact on the convergence of the final solution to near optimal solution. To prove the efficiency of the proposed oppositional-based ALO (OALO) algorithm, three different cases of IEEE standard generator system with and without valve-point loading effects are considered and the proposed algorithm is compared with ALO and KGMO. The main conclusions drawn from the above work are listed below:

- The modification in ALO algorithm enhances the local search exploration capability of the algorithm.
- The convergence rate of the algorithm is higher for proposed OALO in comparison to ALO and KGMO.
- OALO is well efficient in solving the ELD problem, since in all cases; the minimum total cost of generation is obtained from this algorithm.
- KGMO algorithm is found to be the worst performer in comparison to others.

- The performance of OALO algorithm is not affected from the change in test systems.

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