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Improved Artificial Bee Colony Algorithm for Non-Convex Economic Power Dispatch Problem

Badr M. Alshammari, T. Guesmi

***Abstract*—**This study presents a modified version of the artificial bee colony (ABC) algorithm by including a local search technique for solving the non-convex economic power dispatch problem. The local search step is incorporated at the end of each iteration. Total system losses, valve-point loading effects and prohibited operating zones have been incorporated in the problem formulation. Thus, the problem becomes highly nonlinear and with discontinuous objective function. The proposed technique is validated using an IEEE benchmark system with ten thermal units. Simulation results demonstrate that the proposed optimization algorithm has better convergence characteristics in comparison with the original ABC algorithm.

***Keywords*—**Economic power dispatch, artificial bee colony, valve-point loading effects, prohibited operating zones.

I. INTRODUCTION

DUE to the excessive increase of fuel prices, the optimal power generation of thermal units with minimum production cost has become necessary. To satisfy this requirement, several research works have been proposed to solve the economic dispatch (ED). Various studies have considered the traditional ED problem where the production cost function of each thermal unit is approximated by a quadratic function [1], [2]. Unfortunately, modern systems are with units that have prohibited operating zones (POZ) due to physical operation limitations. In addition, practical ED problem includes the valve-point loading effects (VPLE) in the cost function. Thus, traditional optimization techniques proposed in the literature, such as Newton methods [3], lambda iteration [4] and linear programming [5], cannot provide the best solution.

In recent years, several intelligent optimization techniques, such as genetic algorithms (GA), particle swarm optimization (PSO), bacterial foraging and simulated annealing have been used to solve non-convex and discontinuous ED problem [6]-[8]. Despite that these metaheuristic methods have shown their ability to converge into reasonable solutions, they do not always guarantee the global optimal solutions. To overcome this drawback, numerous modified algorithms have been appeared. A combination of GA and micro-GA to improve global and local solution of ED problem is proposed in [9]. An elitist real-coded GA based on non-uniform arithmetic crossover and mutation has been used to optimally schedule the generation of all generators of the IEEE 25-bus system [10]. A hybrid differential evolution and sequential quadratic programming for solving the power dispatch problem is suggested in [11]. In [12], the variable neighborhood search method is incorporated in the differential evolution algorithm in order to improve the optimal solution. Other modified and hybrid techniques combine different metaheuristic algorithms have been presented in the past two decades to solve various form of the ED problem, such as combined hybrid differential PSO algorithm [13], PSO with Time Varying Operators [14], hybrid PSO and gravitational search algorithm [15] and hybrid ant colony optimization- ABC -harmonic search algorithm [16].

Recently, a swarm based stochastic search algorithm called ABC that imitates the foraging behavior of bee colony [17], [18] is considered as an efficient technique for complex optimization problem. However, the ABC algorithm has been criticized to its poor convergence rate and premature convergence due to the unbalanced exploration-exploitation processes. To overcome this disadvantage, a modified ABC algorithm is proposed in this paper for the ED problem. This algorithm incorporates a local search technique at the end of each iteration to facilitate the convergence into the global optimum. VPLE and POZ constraints have been included in the problem. The validation of the proposed optimization method has been evaluated on the well-known benchmark system with ten units.

II. ED PROBLEM FORMULATION

The ED problem is considered as an optimization problem that aims to schedule the outputs of the thermal units so as to minimize the total fuel cost subject to the system operating constraints, such as generation capacity, power balance, POZ and VPLE constraints.

A. Total Fuel Cost Function

Let's consider a power system with N units. The total fuel cost in $/h including VPLE can be expressed by [19]:

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

where, a_i, b_i, c_i, d_i and e_i are the cost coefficients of the i-th unit. P_i is the output power in MW.

B. Problem Constraints

- Unit capacity constraints

$$P_i^{\min} \le P_i \le P_i^{\max}, \; i = 1, \ldots, N \tag{2}$$

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where, $P_i^{\min}$ and $P_i^{\max}$ are respectively, lower and upper generation limits of the *i*-th generator.

- Power balance constraint

$$\sum_{i=1}^{N} P_i - P_D - P_L = 0 \tag{3}$$

where, P_D is total demand power. P_L is the total system losses calculated using the following constant loss formula [20].

$$P_L = \sum_{i=1}^{N}\sum_{j=1}^{N} P_i B_{ij} P_j + \sum_{i=1}^{N} B_{oi} P_i + B_{oo} \tag{4}$$

where B_{ij} , B_{oi} and B_{oo} are the loss-coefficient matrix.

- POZ constraints: The POZ constraints for the *i*-th unit due to the vibrations in the shaft are described in:

$$P_i \in \begin{cases} P_i^{\min} \le P_i \le P_{i,1}^{down} \\ P_{i,k-1}^{up} \le P_i \le P_{i,k}^{down} \quad ,k = 2,\dots,z_i \\ P_{i,z_i}^{up} \le P_i \le P_i^{\max} \end{cases} \tag{5}$$

where, z_i is the number of the POZs for the *i*-th unit. $P_{i,k}^{down}$ and $P_{i,k}^{up}$ are respectively, minimum and maximum limits of the *k*-th POZ.

By considering POZ constraints, the generator will have discontinuous input–output characteristics as shown in Fig. 1.

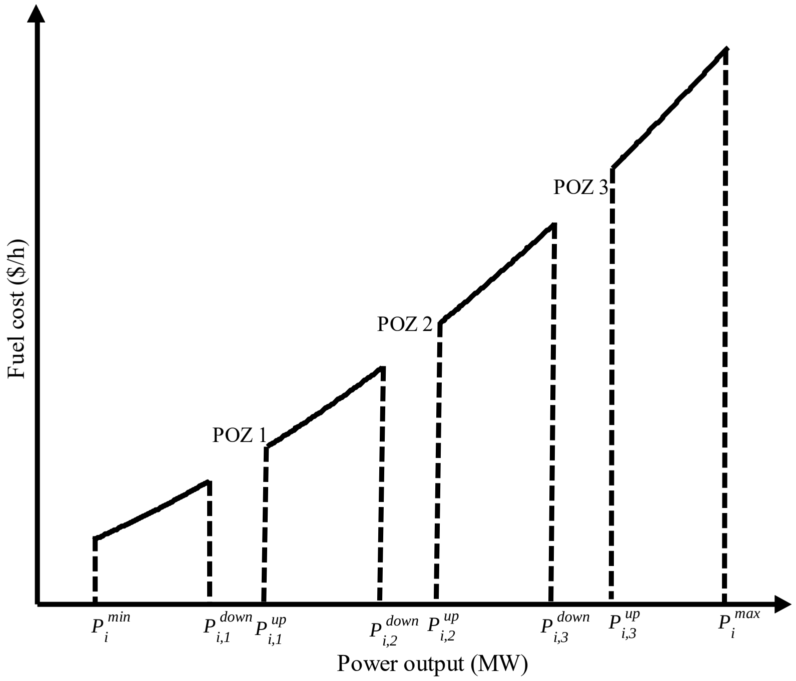

Fig. 1 Input-output characteristic

III. PROPOSED OPTIMIZATION TECHNIQUE

A. Original ABC

ABC algorithm firstly introduced by Karaboga [17] is one of the newest swarm-based techniques. Its main algorithm structure consists of four steps.

Step 1: Initialization Phase

ABC algorithms start by generating *SN* food sources and all algorithm parameters. Each food source $X^i = [x_1^i, x_2^i, \cdots, x_D^i]$ is considered as solution and it is generated randomly on the *D*-dimensional problem space as given in (6):

$$x_j^i = X_j^{\min} + rand(0,1)\left(X_j^{\max} - X_j^{\min}\right) \tag{6}$$

where $X_j^{\min}$ and $X_j^{\max}$ are limits of the food source in dimension *j*.

The fitness function of each solution X^i that corresponds to the objective function is assumed as the nectar amount evaluated by an employed bee on the food source. It can be calculated as:

$$fit\left(X^i\right) = \begin{cases} \dfrac{1}{1+f\left(X^i\right)}, & f\left(X^i\right) \ge 0 \\ 1+\left|f\left(X^i\right)\right|, & f\left(X^i\right) < 0 \end{cases} \tag{7}$$

where *f* is the objective function.

Step 2: Employed Bees' Phase

Each employed bee tries to update each selected food source X^i in order to find better location close to this source. The updated food source V^i is determined as:

$$v_j^i = x_j^i + \varphi_j^i \left(x_j^i - x_j^k \right) \tag{8}$$

Indices *k* and *j* are chosen randomly from $\{1,2,...,SN\}$ and $\{1,2,...,D\}$, respectively. φ_j^i is a uniform real number in the range of $[0,1]$.

Step 3: Onlooker Bees' Phase

In this step, each onlooker bee selects the food source based on the nectar amount. The probability of selection of a food source X^i is given in (9):

$$p_i = \frac{fit\left(X^i\right)}{\sum_{n=1}^{SN} fit\left(X^n\right)} \tag{9}$$

The selected food source will be updated using (8). During this step, a greedy selection is applied between V^i and X^i.

Step 4: Scoot Bees' Phase

If an onlooker that its food source cannot be improved in the last step, it will be converted to a scout bee and it starts to search another source using (6).

B. Modified ABC Algorithm

The main drawback addressed to the classical ABC algorithm is the random selection of the *j*-th dimension in the employed and onlooker bees' phases. The random selection of this parameter causes a slow convergence rate. Within this context, this paper proposes a search method called local search technique. Instead of replacing the *j*-th dimension, the whole food source will be updated. The flowchart of the local search method applied in this study to update each food source is described in Fig. 2.

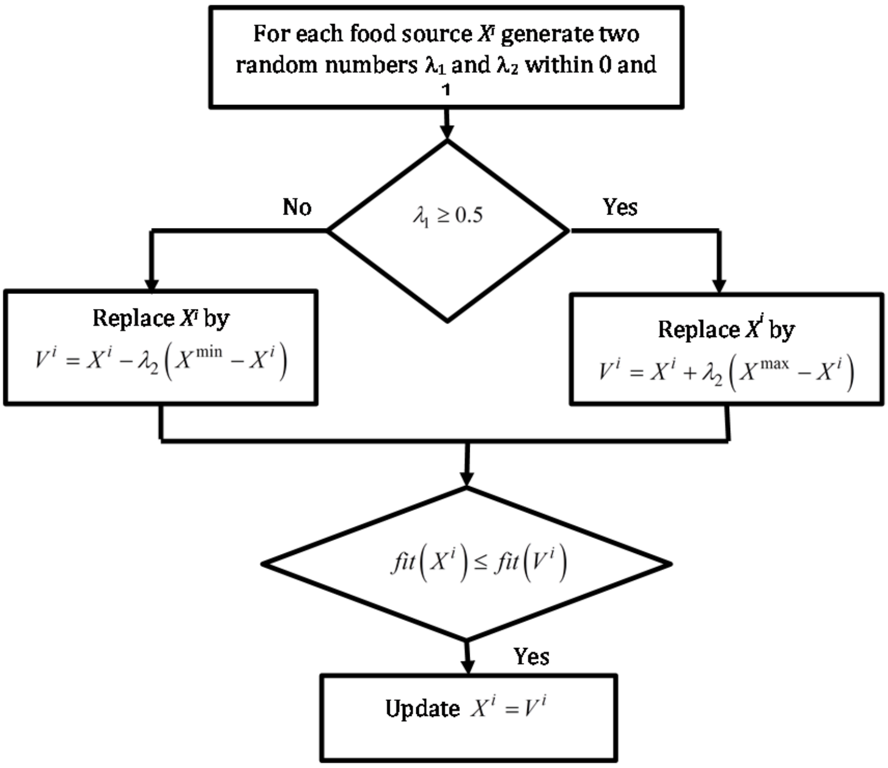

Fig. 2 Local search method

IV. SIMULATION RESULTS

The proposed modified ABC algorithm with local search (ABC-LS) for solving ED problem is validated using the benchmark test system comprising ten thermal units with VPLE and POZs. The system data are taken from [21] and given in Table I. A comparison of the proposed technique with the classical ABC algorithm is presented in this section to demonstrate its effectiveness in finding the best optimum solution. The B-loss matrix of the ten-unit system is described in (10):

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$$B = 10^{-4}\begin{bmatrix} 0.49 & 0.14 & 0.15 & 0.15 & 0.16 & 0.17 & 0.17 & 0.18 & 0.19 & 0.20 \\ 0.14 & 0.45 & 0.16 & 0.16 & 0.17 & 0.15 & 0.15 & 0.16 & 0.18 & 0.18 \\ 0.15 & 0.16 & 0.39 & 0.10 & 0.12 & 0.12 & 0.14 & 0.14 & 0.16 & 0.16 \\ 0.15 & 0.16 & 0.10 & 0.40 & 0.14 & 0.10 & 0.11 & 0.12 & 0.14 & 0.15 \\ 0.16 & 0.17 & 0.12 & 0.14 & 0.35 & 0.11 & 0.13 & 0.13 & 0.15 & 0.16 \\ 0.17 & 0.15 & 0.12 & 0.10 & 0.11 & 0.36 & 0.12 & 0.12 & 0.14 & 0.15 \\ 0.17 & 0.15 & 0.14 & 0.11 & 0.13 & 0.12 & 0.38 & 0.16 & 0.16 & 0.18 \\ 0.18 & 0.16 & 0.14 & 0.12 & 0.13 & 0.12 & 0.16 & 0.40 & 0.15 & 0.16 \\ 0.19 & 0.18 & 0.16 & 0.14 & 0.15 & 0.14 & 0.16 & 0.15 & 0.42 & 0.19 \\ 0.20 & 0.18 & 0.16 & 0.15 & 0.16 & 0.15 & 0.18 & 0.16 & 0.19 & 0.44 \end{bmatrix} \quad (10)$$

Two cases have been considered in this study.

A. Case 1: Without POZs Constraints

Fig. 3 shows the convergence of the total cost for total demand power of 1000 MW using ABC-LS and ABC algorithms. It is evident that the proposed algorithm gives the best solution. It can be seen that the minimum total cost when using ABC-LS is 59380.69 \$/h, while it is 59413.58 \$/h for classical ABC.

Optimum solutions for various loads are given in Table II. Form this table, it is clear that generation limits are considered and the ABC-LS provides the best results for all loads.

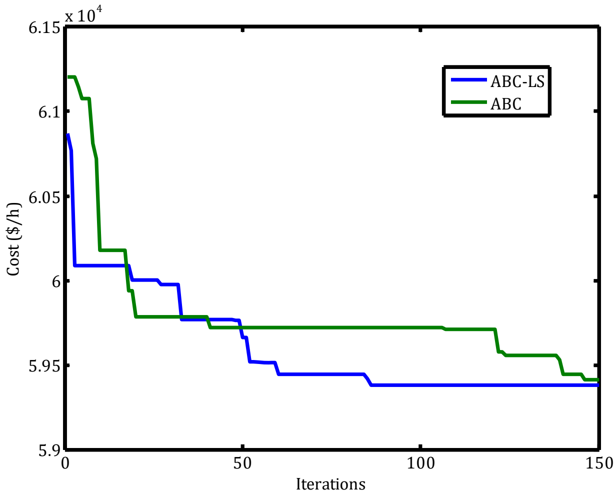

Fig. 3 Cost convergence for PD = 1000 MW

TABLE I
SYSTEM DATA

Unit	A	b	c	d	E	$P_i^{\min}$ (MW)	$P_i^{\max}$ (MW)	Prohibited zone (MW)
1	786.7988	38.5397	0.1524	450	0.041	150	470	[150 165], [448 453]
2	451.3251	46.1591	0.1058	600	0.036	135	470	[90 110], [240 250]
3	1049.9977	40.3965	0.0280	320	0.028	73	340	-
4	1243.5311	38.3055	0.0354	260	0.052	60	300	-
5	1658.5696	36.3278	0.0211	280	0.063	73	243	-
6	1356.6592	38.2704	0.0179	310	0.048	57	160	-
7	1450.7045	36.5104	0.0121	300	0.086	20	130	-
8	1450.7045	36.5104	0.0121	340	0.082	47	120	[20 30], [40 45]
9	1455.6056	39.5804	0.1090	270	0.098	20	80	-
10	1469.4026	40.5407	0.1295	380	0.094	10	55	[12 17], [35 45]

TABLE II
OPTIMUM SOLUTION IN MW WITHOUT POZS CONSTRAINTS

P_D (MW)	1000		1200		1400		1600	
Method	ABC-LS	ABC	ABC-LS	ABC	ABC-LS	ABC	ABC-LS	ABC
P_1	150.3980	150.2608	50.1183	150.1993	150.1176	150.1631	150.2688	150.4402
P_2	135.0000	135.0000	135.0000	135.0000	135.0000	135.0000	135.0000	135.0000
P_3	73.8300	79.5581	182.6786	79.4907	190.8530	195.7603	298.3047	294.5893
P_4	60.0000	60.0000	119.2166	173.3380	184.1652	181.3227	300.0000	300.0000
P_5	172.0393	173.6729	172.4413	221.4741	242.5004	243.0000	231.0179	235.2401
P_6	115.2207	139.9312	121.2681	123.1007	159.5337	156.8323	157.8854	157.8426
P_7	130.0000	130.0000	129.4122	128.2707	130.0000	130.0000	129.4678	129.7292
P_8	120.0000	120.0000	119.9208	119.1100	120.0000	119.9977	120.0000	120.0000
P_9	52.0065	20.0000	52.2784	53.2920	79.5927	79.2334	80.0000	80.0000
P_{10}	10.0000	10.0000	43.7297	42.9229	43.4245	43.8966	44.3790	43.4682
Cost	59380.69	59413.58	68987.01	69111.71	79593.61	79650.95	91123.12	91128.65
Losses	18.4943	18.4230	26.0641	26.1984	35.1870	35.2061	46.3235	46.3095

TABLE III
OPTIMUM SOLUTION WITH POZS CONSTRAINTS

P_D	1000		1200		1400		1600	
Method	ABC-LS	ABC	ABC-LS	ABC	ABC-LS	ABC	ABC-LS	ABC
P_1	165.1204	165.1523	165.2710	165.1318	165.0909	165.0722	166.6105	165.3441
P_2	135.0000	135.0000	135.0000	135.1689	135.0734	135.0000	135.0000	135.0000
P_3	76.5427	74.1883	173.3861	86.3128	199.5952	189.7696	295.6962	302.1017
P_4	64.9224	133.8604	124.3907	180.6893	182.8316	181.9040	300.0000	266.8232
P_5	173.8728	73.0000	228.8840	229.2110	223.6764	222.9506	243.0000	242.3350
P_6	123.1177	122.6770	122.9827	123.1096	159.8934	159.2527	159.6806	159.7217
P_7	130.0000	130.0000	127.9262	130.0000	129.2105	129.5609	129.6302	129.8065
P_8	120.0000	120.0000	117.4995	119.4790	120.0000	119.9245	119.1480	120.0000
P_9	20.0000	54.5960	20.8457	47.1720	74.5740	79.2713	52.1945	79.9178
P_{10}	10.0000	10.0000	10.0000	10.0000	45.3529	52.6214	45.4802	45.3456
Cost	60140.41	60726.68	70003.49	70024.86	80447.9	80499.54	91921.37	92055.08
Losses	18.5759	18.4740	26.1858	26.2744	35.2982	35.3272	46.4403	46.3956

B. Case 2: With POZs Constraints

In this case, POZs constraints have been considered in the ED problem. Optimum generated powers obtained using ABC-LS and ABC algorithms are depicted in Table III. It is observed that the proposed method outperforms the classical ABC. In order to examine the impact of POZs constraints on the ED problem solution, the variation of the difference ΔC in $/h between costs obtained using the proposed algorithm for the cases with and without POZs, versus various loads has been illustrated in Fig. 4. It can be seen that ΔC is positive for all loads. Thus, we can conclude that when POZs are included in the problem, the optimum cost increases due to the limitation of the search space.

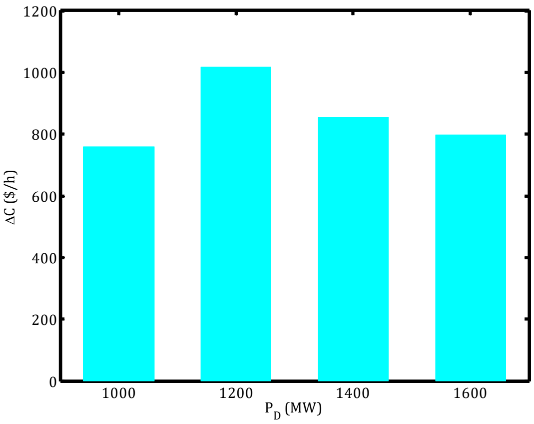

Fig. 4 Effect of POZs on the optimum cost

V. CONCLUSION

In this paper an ABC based approach is proposed to solve the non-smooth and non-convex economic power dispatch (EPD). This technique combines the ABC algorithm and a local search method in order to improve the exploration of the search space. The EPD problem has been converted in to a mono-objective optimization problem that aims to minimize total production cost. VPLE, total power losses and other operating constraints have been considered. The mentioned problem is solved with and without considering POZ.

Simulations results are carried out using the ten-unit system for various loads. It is observed that:

- The optimum cost increases when POZs have been considered due to the reduction of the search space.
- The technique outperforms the original ABC algorithm.

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