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) problem. 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]:

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

(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

\[
P_i^{\text{min}} \leq P_i \leq P_i^{\text{max}}, \quad i = 1, \ldots, N
\]  

(2)

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

- **Power balance constraint**

\[
\sum_{i=1}^{N} P_i - P_D - P_L = 0 \quad (3)
\]

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

\[
P_L = \sum_{i=1}^{N} \sum_{j=1}^{N} P_{ij} B_{ij} P_i + \sum_{i=1}^{N} B_{oi} P_i + B_{oo} \quad (4)
\]

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:

\[
P_i \in \begin{cases} 
P_i^{\text{min}} \leq P_i \leq P_i^{\text{down}} \\
P_i^{\text{up}} \leq P_i \leq P_i^{\text{max}} 
\end{cases}, k = 2, ..., z_i \quad (5)
\]

where, \( z_i \) is the number of the POZs for the \( i \)-th unit. \( P_i^{\text{down}} \) and \( P_i^{\text{up}} \) 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.

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**Fig. 1** Input-output characteristic

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**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.

1. **Step 1: Initialization Phase**

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

\[
x_j^i = X_j^{\text{min}} + \text{rand}(0,1)(X_j^{\text{max}} - X_j^{\text{min}}) \quad (6)
\]

where \( X_j^{\text{min}} \) and \( X_j^{\text{max}} \) 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:

\[
\text{fit}(X^i) = \begin{cases} 
\frac{1}{1 + |f(X^i)|}, & f(X^i) \geq 0 \\
\frac{1}{1 + |f(X^i)|}, & f(X^i) < 0
\end{cases} \quad (7)
\]

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:

$$V^i = x^i_j + \varphi^i_j \left(x^i_j - x^k_j\right)$$ \hspace{1cm} (8)

Indices $k$ and $j$ are chosen randomly from $\{1, 2, \ldots, SN\}$ and $\{1, 2, \ldots, D\}$, respectively. $\varphi^i_j$ 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):

$$p_i = \frac{fit(X^i)}{\sum_{n=1}^{SN} fit(X^n)}$$ \hspace{1cm} (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: Scout 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.

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):
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. From this table, it is clear that generation limits are considered and the ABC-LS provides the best results for all loads.

### TABLE I

<table>
<thead>
<tr>
<th>System Data</th>
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<tr>
<td>Unit</td>
<td>A</td>
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<tr>
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<tr>
<td>2</td>
<td>451.3251</td>
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<tr>
<td>9</td>
<td>1455.6056</td>
</tr>
<tr>
<td>10</td>
<td>1469.4026</td>
</tr>
</tbody>
</table>

### TABLE II

| Optimum Solution in MW without POZs Constraints |
|---|---|---|---|
| P<sub>d</sub> (MW) | 1000 | 1200 | 1400 |
| Method | ABC-LS | ABC-LS | ABC-LS | ABC-LS | ABC-LS | ABC-LS |
| P<sub>1</sub> | 150.3980 | 150.2608 | 150.1993 | 150.176 | 150.163 | 150.268 |
| P<sub>2</sub> | 135.0000 | 135.0000 | 135.0000 | 135.0000 | 135.0000 | 135.0000 |
| P<sub>3</sub> | 73.8300 | 79.5581 | 182.6786 | 79.4907 | 190.8530 | 298.3047 |
| P<sub>4</sub> | 60.0000 | 60.0000 | 119.2166 | 79.4907 | 190.8530 | 298.3047 |
| P<sub>5</sub> | 172.0393 | 173.6279 | 172.4413 | 221.4741 | 184.1652 | 181.3227 |
| P<sub>6</sub> | 115.2207 | 139.9312 | 121.2681 | 173.3380 | 184.1652 | 181.3227 |
| P<sub>7</sub> | 130.0000 | 130.0000 | 129.4122 | 123.1072 | 130.0000 | 130.0000 |
| P<sub>8</sub> | 120.0000 | 120.0000 | 119.9208 | 119.1100 | 120.0000 | 119.977 |
| P<sub>9</sub> | 10.0000 | 10.0000 | 43.7297 | 42.9229 | 43.4245 | 43.8966 |
| Cost | 59380.69 | 59413.58 | 68987.01 | 69111.71 | 79593.61 | 79650.95 |

Fig. 3 Cost convergence for PD = 1000 MW
In this paper an ABC based approach is proposed to solve the economic dispatch problem, utilizing ABC, a metaheuristic algorithm, to solve the optimization problem. The approach considers prohibited operating zones (POZs) constraints, which are crucial for realistic power system operation. The proposed method outperforms classical ABC algorithms, as demonstrated through simulations on a ten-unit system.

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

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

### REFERENCES


### B. Case 2: With POZs Constraints

In this case, POZs constraints have been considered in the economic dispatch 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 economic dispatch problem solution, the variation of the difference $\Delta C$ 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 $\Delta C$ 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.

### Table III: Optimum Solution with POZs Constraints

<table>
<thead>
<tr>
<th>$P_L$</th>
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<th>1200</th>
<th>1400</th>
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<td>165.2710</td>
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<td>165.0909</td>
<td>165.0722</td>
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<tr>
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<td>200.0000</td>
<td>200.0000</td>
<td>200.0000</td>
</tr>
<tr>
<td>ABC</td>
<td>200.0000</td>
<td>200.0000</td>
<td>200.0000</td>
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</tbody>
</table>

### 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.

![Fig. 4 Effect of POZs on the optimum cost](image-url)


