# Solving various types of economic dispatch problem using Bees algorithm

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***Abstract*-This paper presents an application of Bees Algorithm (BA) for solving various types of Economic Dispatch (ED) problem. Complete ED problem formulation prohibited, operating zones, ramp-rate limits, and non-smooth or non-convex cost functions arising from the use of multiple fuels should be taken into consideration. To show its efficiency, the Bee algorithm is applied to solve various types ED problems of power systems. The simulation results obtained from the BA are compared to those achieved from the conventional approaches, such as simulated annealing (SA) genetic algorithm (GA), tabu search (TS) algorithm and particle swarm optimization (PSO). The experimental results show that the BA approach is able to obtain higher quality solution efficiently and faster computational time than the conventional approaches.**

## I. INTRODUCTION

The economic dispatch (ED) problem is an important optimization problem. Moreover, it has complex and nonlinear characteristics with heavy equality and inequality constraints. To solve the ED problem, various conventional methods such as the lambda-iteration methods, the gradient method, and dynamic programming (DP) etc, have been employed [1,2]. Unfortunately, for the generating units with nonlinear characteristics, such as ramp rate limits, prohibited operating zones, and non-convex cost functions, the conventional methods can hardly achieve the optimal or near optimal solution. Furthermore, for a large-scale system, the conventional methods have oscillatory problem resulting in a local minimum solution or a longer computational time.

In the past decade, many nature inspired algorithms were developed like simulated annealing (SA) [3], genetic algorithm (GA) [4,5] , Tabu search (TS) algorithm [6] and particle swarm optimization (PSO) [7], which are probabilistic heuristic algorithms, have been successfully used to solve the ED problem. These algorithms can provide far better solution in comparison to classical algorithm.

A branch of nature inspired algorithms which are known as Swarm Intelligence is focused on insect behavior in order to develop some meta-heuristics such as Particle Swarm Optimization (PSO) etc. The honey Bees Algorithm (BA) was proposed by Pham D.T [8] in 2005. It is a relatively new member of Swarm Intelligence. The Bees algorithm mimics the food foraging behavior of swarms of honey bees. Honey bees use several mechanisms like waggle dance to optimally locate food sources and to search new ones. This algorithm is a very simple, robust and population based stochastic optimization algorithm.

The feasibility study of the BA is demonstrated for solving the ED problem. The results optimized by the BA are compared to those obtained by the conventional approaches such as SA, GA, TS and PSO in terms of solution quality and computational efficiency.

The paper is organized as follows. Section II gives the mathematical model of the constrained ED problem. Section III presents the detailed procedures of using the Bees algorithm to solve the ED problem. Section IV shows two application cases and gives the corresponding comparison results with the traditional methods (SA, GA, TS and PSO). Conclusion is finally given in Section V.

## II. ECONOMIC DISPATCH PROBLEM FORMULATION

The objective of ED problem is to find the optimal combination of power generation that minimizes the total generation cost while to satisfy the system load demand, spinning reserve capacity, and practical operation constraints of generators that include the ramp rate limit and the prohibited operating zone [7].

### *A. Objective Function*

The objective function of ED problem can be modified as

$$\min F_t = \sum_{i=1}^{m} F_i(P_i) = \sum_{i=1}^{m} (a_i + b_i P_i + c_i P_i^2) \quad (1)$$

where $F_t$ is the total generation cost; $F_i$ is the generation cost function of $i^{th}$ generator is usually expressed as a quadratic polynomial; $a_i, b_i$, and $c_i$ are the cost coefficients of the $i^{th}$ generator; $P_i$ is the power output of the $i^{th}$ generator and $m$ is the number of generators committed to the operating system.

To take account for the valve-point effects, sinusoidal functions are added to the quadratic cost functions as follows,

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

where $e_i$ and $f_i$ are the valve-point coefficients.

Generally, a piecewise quadratic function is used to represent the input-output curve of a generator with multiple fuels [11]. The piecewise quadratic function is described by

$$F_i(P_i) = \begin{cases} a_{i1} + b_{i1} P_i + c_{i1} P_i^2 & P_i^{\min} \le P_i \le P_{i1} \\ a_{i2} + b_{i2} P_i + c_{i2} P_i^2 & P_{i1} \le P_i \le P_{i2} \\ \vdots & \vdots \\ a_{ik} + b_{ik} P_i + c_{ik} P_i^2 & P_{ik-1} \le P_i \le P_i^{\max} \end{cases} \quad (3)$$

where $a_{ij}$, $b_{ij}$, and $c_{ij}$ are the cost coefficients of the $i^{th}$ generator for the $j^{th}$ power level.

### B. Constraints

#### 1) Power Balance Constraints

$$\sum_{i=1}^{m} P_i = P_D + P_L \tag{4}$$

where $P_D$ is the load demand and $P_L$ is the total transmission network losses, which is a function of unit power outputs that can be represented using $B$ coefficients:

$$P_L = \sum_{i=1}^{m}\sum_{j=1}^{m} P_i B_{ij} P_j + \sum_{i=1}^{m} B_{0i} P_i + B_{00} \tag{5}$$

#### 2) Practical Operation Constraints of Generator

To achieve the actual economic operation, the two constraints of generator operation are taken into account.

*a) Ramp Rate Limits*: The ramp rate of generating units is caused by the fact that the thermal generating outputs can not be adjusted instantaneously. To reflect the actual operating process, the ramp rate limits are included in the ED problem to ensure the feasibility of solutions. The operating range of all on-line units is restricted by their ramp rate limits. According to [7], the inequality constraints due to ramp rate limits for unit generation changes are given as

$$\max(P_i^{\min}, P_i^0 - DR_i) \le P_i \le \min(P_i^{\max}, P_i^0 + UR_i) \tag{6}$$

where $P_i^0$ is the previous output power. $P_i^{\min}$, $P_i^{\max}$ are the minimum and maximum output of $i$ th generator, respectively. $UR_i$, $DR_i$ are the up-ramp and down-ramp limit of $i$ th generator (MW/time period), respectively.

*b) Prohibited Operating Zone*: The prohibited operating zones in the curve are due to steam valve operating or vibration in a shaft bearing [7]. In practice, the shape of the input-output curve in the neighborhood of the prohibited zone is difficult to determine by actual performance testing or operating records. In the actual operation, adjusting the generation output $P_i$ of a unit must avoid unit operation in the prohibited zones. The feasible operating zones of unit $i$ can be described as follows:

$$P_i \in \begin{cases} P_i^{\min} \le P_i \le P_{i,1}^{l} \\ P_{i,j-1}^{u} \le P_i \le P_{i,j}^{l},\ j = 2,3,\ldots,n_i \\ P_{i,n_i}^{u} \le P_i \le P_i^{\max} \end{cases} \tag{7}$$

where $n_i$ is the number of prohibited zones of $i$ th generator. $P_{i,j}^{l}$, $P_{i,j}^{u}$ are the lower and upper power output of prohibited zones $j$ of $i$ th generator, respectively.

## III. Bees Algorithm to Solve ED Problem

### A. Principle of Bees algorithm

The algorithm mimics the food foraging behavior of swarms of honey bees. Honey bees use several mechanisms like waggle dance to optimally locate food sources and to search new ones. This makes them a good candidate for developing new intelligent search algorithms. It is a very simple, robust and population based stochastic optimization algorithm.

In Bees algorithm, the colony of artificial bees contains two groups of bees are scout and employed bees. The scout bees have the responsibility is to find a new food source. The responsibility of employed bees is to determine a food source within the neighbourhood of the food source in their memory and share their information with other bees within the hive.

### B. Bees algorithm to solve ED problem

An application of Bees algorithm is described for solving the ED problems. Especially, a suggestion about how to deal with the equality and inequality constraints of the ED problems when each search point is modified in the Bees algorithm is also given.

The algorithm requires a number of parameters to be set, namely: $NC$ is number of iteration, $n_S$ is number of scout bees, $m$ is number of sites selected out of $n_S$ visited sites, $e$ is number of best sites out of m selected sites, $nep$ is number of bees recruited for best $e$ sites, $nsp$ is number of bees recruited for the other ($m$-$e$) selected sites, $ngh$ is initial size of patches which includes site and its neighborhood and stopping criterion.

In this paper, the structure of a solution for ED problem is composed of a set of generation outputs. Therefore, the initial solutions of $n_S$ scout bees can be represented as the vector of $X_i^k = (P_{i1}^k, \ldots, P_{in}^k)$, $i = 1, \ldots, n_S$ where $n_S$ is the number of scout bees and $n$ is the number of generators. Note that it is very important to create a set of solution satisfying the equality constraint and inequality constraints. The process of the Bees algorithm can be summarized as follows:

***Step 1:*** Generate randomly the initial populations of $n$ scout bees. These initial populations must be feasible candidate solutions that satisfy the constraints. Set $NC = 0$.

***Step 2:*** Evaluate the fitness value of the initial populations.

***Step 3:*** Select $m$ best solutions for neighbourhood search.

***Step 4:*** Separated the $m$ best solutions to two groups, the first group have $e$ best solutions and another group has $m-e$ best solutions.

***Step 5:*** Determine the size of neighbourhood search of each best solutions ($ngh$).

***Step 6:*** Generate solutions around the selected solutions within neighbourhood size.

***Step 7:*** Select the fittest solution from each patch.

***Step 8:*** Check the stopping criterion. If satisfied, terminate the search, else $NC = NC + 1$.

***Step 9:*** Assign the $n-m$ population to generate new solutions. Go to Step 2.

## IV. TEST RESULTS AND DISCUSSIONS

To assess the feasibility of the BA method, it has been applied to solve the ED problem on three different power system types and made comparison with SA, GA, TS and PSO. All methods are performed 100 trials, under the same evaluation function and individual definition, in order to compare their solution quality, convergence characteristic, and computation efficiency. The software was implemented by MATLAB® languages on Intel® Core2 Duo 1.66 GHz Laptop with 2 GB RAM under Windows XP.

Table 1. parameters setting of the BA algorithm

| Bees Algorithm parameters | Symbol | Value/range |
|---|---|---|
| Population | n | 20 |
| Number of selected sites | m | 6 |
| Number of elite site | e | 1 |
| Patch size | ngh | 0.01 |
| Number of bees around elite site | nep | 10 |
| Number of bees around other selected site | nsp | 2 |
| Maximum number of iteration | itermax | 100 |

*Example 1*: The system contains 15 thermal units whose characteristics and the loss coefficients $B$ matrices are shown in. [7]. The load demand is 2,630 MW. To simulation this case, each individual $P_g$ contains 15 generator power outputs. The best solution (MW) obtained by BA satisfies with the system constraints such as the ramp rate limits and prohibited zones of units:

$P_1 = 453.99$, $P_2 = 379.74$, $P_3 = 130.00$, $P_4 = 129.92$, $P_5 = 168.08$, $P_6 = 460.00$, $P_7 = 429.22$, $P_8 = 104.30$, $P_9 = 35.03$, $P_{10} = 155.88$, $P_{11} = 79.90$, $P_{12} = 79.90$, $P_{13} = 25.02$, $P_{14} = 15.25$, and $P_{15} = 15.08$

Table 2. provides the statistic results with 100 trials such as the generation cost, standard deviation, computational time and percentage of approaching near optimal solution.

Table 2. Performance Comparison of 15 units system.

| Methods | Max. Cost ($/h) | Average Cost ($/h) | Min. Cost ($/h) | Standard Deviation | CPU time (s) |
|---|---|---|---|---|---|
| **SA** | 33,028.95 | 32,869.51 | 32,786.40 | 112.32 | 71.25 |
| **GA** | 33,041.64 | 32,841.21 | 32,779.81 | 81.22 | 48.17 |
| **TSA** | 32,942.71 | 32,822.84 | 32,762.12 | 60.59 | 26.41 |
| **PSO** | 32,841.38 | 32,807.45 | 32,724.17 | 21.24 | 13.25 |
| **BA** | **32,796.15** | **32,767.21** | **32,716.87** | **17.51** | **3.65** |

*Example 2*: The 40-unit system with valve-point effects is considered. The input data for 40 generating units system are given in [9] with 10,500 MW load demand. The global solutions for these systems are not discovered yet. The best local solutions reported until now for 40 generating units is 121,741.98 $/h [10], respectively. After performing 100 trials, the best solutions (MW) obtained by BA for 40 units are 121,532.41 $/h, as below:

$P_1 = 110.80$, $P_2 = 111.80$, $P_3 = 97.80$, $P_4 = 179.84$, $P_5 = 92.70$, $P_6 = 139.96$, $P_7 = 299.96$, $P_8 = 299.88$, $P_9 = 284.48$, $P_{10} = 131.80$, $P_{11} = 168.00$, $P_{12} = 94.28$, $P_{13} = 214.22$, $P_{14} = 393.44$, $P_{15} = 304.16$, $P_{16} = 304.76$, $P_{17} = 489.00$, $P_{18} = 490.60$, $P_{19} = 511.44$, $P_{20} = 511.20$, $P_{21} = 524.60$, $P_{22} = 523.70$, $P_{23} = 523.70$, $P_{24} = 524.20$, $P_{25} = 524.00$, $P_{26} = 524.00$, $P_{27} = 13.20$, $P_{28} = 10.00$, $P_{29} = 11.60$, $P_{30} = 90.80$, $P_{31} = 189.50$, $P_{32} = 189.50$, $P_{33} = 186.50$, $P_{34} = 199.00$, $P_{35} = 197.50$, $P_{36} = 198.30$, $P_{37} = 109.70$, $P_{38} = 109.90$, $P_{39} = 108.90$, $P_{40} = 511.44$,

The comparison results of the BA with other four methods are given in Table 3. The results show that the BA succeeds in finding the best solution. The worst, average, and best values of the generation costs achieved by BA for 100 runs are much better than those of other methods. Besides, the lowest standard deviation (Std.) and the highest robustness of the solutions obtained by BA.

Table 3. Convergence results for 40-unit system.

| Methods | Load demand = 10,500 MW | | | | |
|---|---|---|---|---|---|
| | Worst | Average | Best | Std. | CPU time |
| SA | 123807.97 | 122919.77 | 121996.40 | 492.11 | 320.31 |
| GA | 122590.89 | 122424.81 | 122288.38 | 88.10 | 238.35 |
| TS | 122000.80 | 121899.57 | 121800.13 | 59.28 | 84.21 |
| PSO | 122048.06 | 121930.58 | 121811.37 | 67.02 | 92.54 |
| **BA** | **121679.64** | **121606.45** | **121532.41** | **45.58** | **52.45** |

*Example 3*: The 10-unit system with multiple-fuel effects is considered. In this case, the objective function is represented by the piecewise quadratic cost function. The input data and related constraints of the test system are given in [11]. In this case, the total system demand is 2,700 MW. After performing 100 trials, the best solution obtained by BA is given in Table 4. The comparison results of the BA with other four methods are given in Table 5. This result signifies that the BA always provides better high quality of solution than other methods. Additionally, the BA converges to the optimum solution much faster than other methods.

Table 4. Best result of 10-unit system ($P_D$ =2700 MW)

| Unit | Fuel | $P_i$ (MW) | Unit | Fuel | $P_i$ (MW) |
|---|---|---|---|---|---|
| 1 | 2 | 221.45 | 6 | 3 | 239.11 |
| 2 | 1 | 211.53 | 7 | 1 | 284.76 |
| 3 | 1 | 281.62 | 8 | 3 | 240.70 |
| 4 | 3 | 239.90 | 9 | 3 | 429.61 |
| 5 | 1 | 276.99 | 10 | 1 | 274.31 |
| Total power output (MW) | | | | | 2700 |
| Total generation cost ($/h) | | | | | 623.7 |

Table 5. Convergence results for 10-unit system ($P_D$ =2700 MW)

| Method | Load demand = 2,700 MW | | | | |
|---|---|---|---|---|---|
| | Worst | Average | Best | Std. | CPU time |
| SA | 626.80 | 625.41 | 623.92 | 0.82 | 50.22 |
| GA | 624.96 | 624.51 | 624.01 | 0.28 | 18.51 |
| TS | 624.89 | 624.39 | 623.81 | 0.30 | 7.28 |
| PSO | 624.78 | 624.35 | 623.90 | 0.24 | 8.35 |
| **BA** | **624.09** | **623.90** | **623.70** | **0.11** | **5.16** |

## V. Conclusions

The Bees algorithm has been applied to solve the various ED problems with taking various generator constraints such as ramp rate limits and prohibited operating zone into consideration. The Bees algorithm shows superior features such as high-quality solution, stable convergence characteristic, and good computation efficiency. The studied results confirm that the proposed BA are indeed capable of obtaining higher quality solution efficiently, convergence characteristic and computation efficiency in comparison with SA, GA, TS and PSO methods.

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