

Gbest Artificial Bee Colony for Non-Convex Optimal Economic Dispatch in Power Generation

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ABSTRACT

Non-convex Optimal Economic Dispatch (OED) problem is a complex optimization problem in power system operation that must be optimized economically to meet the power demand and system constraints. The non-convex OED is due to the generator characteristic such as prohibited operation zones, valve point effects (VPE) or multiple fuel options. This paper proposes a Gbest Artificial Bee Colony (GABC) algorithm based on global best particle (gbest) guided of Particle Swarm Optimization (PSO) in Artificial bee colony (ABC) algorithm for solving non-convex OED with VPE. In order to investigate the effectiveness and performance of GABC algorithm, the IEEE 14-bus 5 unit generators and IEEE 30-bus 6 unit generators test systems are considered. The comparison of optimal solution, convergence characteristic and robustness are also highlighted to reveal the advantages of GABC. Moreover, the optimal results obtained by proposed GABC are compared with other reported results of meta-heuristic algorithms. It found that the GABC capable to obtain lowest cost as compared to others. Thus, it has great potential to be implemented in different types of power system optimization problem.

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1. INTRODUCTION

Power dispatch is one of the optimization problem in power system planning and operation. It is important to ensure that total cost of power generation can be minimize as much as possible to gain high profit to power company as known as optimal economic dispatch (OED) problem. Reduction of fossil fuels resources and high fuel prices encourage utility to operate the system at minimum cost as well as satisfied all the system and operational constraints. Commonly, the cost function of thermal generator is modelled as quadratic function that can be solve efficiently by most of the conventional methods such lambda iteration method [1], linear programming [2], quadratic programming [3] and other methods that can be found in [4] [5, 6].

However, these methods shows difficulty to obtain optimal results when the non-linear characteristic are taken into account in cost modelling such valve point effect (VPE), prohibited operating zone (POZ) or multiple fuels option (MFO) [7]. In practical, generators used multi-valve turbine that produced several ripples in heat-rate characteristic as well as cost-power characteristic that contributes a combination of sinusoidal and quadratic cost function. Therefore, it challenges most optimization algorithms to obtained optimal solution in OED problem.

Due to this problem, most of researchers use the meta-heuristics algorithms that can search the optimal solution without depending to the convexity of the cost function such as Genetic Algorithm, Particle Swarm Optimization (PSO) [8, 9], Cuckoo Search (CS) [10], Artificial Bee Colony (ABC) [11], Backtracking Search Algorithm (BSA) [12] and Rooted Tree Algorithm (TRO) [13]. However, in some cases these algorithms are suffered and converged at local optimal solution. As a results, many improvement of original algorithm have been proposed by researchers to improve the performance of original algorithm [14] [15] [7]. To have balance exploration and exploitation capability of original ABC, the Gbest Artificial Bee Colony (GABC) [16] has been introduced and successfully solve numerical function optimization problem. The GABC is guided the ABC algorithm based on the global best solution (gbest) in PSO algorithm in order to enhance the exploitation capability of ABC. It also promises a good result for finding optimal economic-emission considering wind in [17] and optimal power flow [18].

This paper proposes a GABC algorithm for solving the non-convex OED problem considering the non-linear cost function due VPE. Theproposed GABC has been validatedon two different test systems. The effectiveness of GABC has compared with original ABC in terms of optimal cost, convergence performance and robustness after 40 trials. Moreover, the obtained optimal results also compared with the some reported result found in literature. It found that, proposed GABC provided significant cost reduction for OED with VPE.

2. PROBLEM FORMULATION: OPTIMAL ECONOMIC DISPATCH (OED)

This section explains the mathematical formulation of OED problem such as objective function and constraints as follows:

2.1. Objective Function of OED

The main objective of OED is to determine the best power output of the scheduled generator so that the power demand and system constraints can be meet in economical way. The cost function commonly formulated as quadratic function. However, the practical cost function become non-linear due to valve point effect (VPE) as shown in Figure 1. Therefore, the objective function of OED problem for minimizing total cost (F_c) of i th generator as follows:

$$F_c = \sum_{i=1}^N F(P_i) = a_i P_i^2 + b_i P_i + c_i + \left| e_i \sin \left[f_i \left(P_i^{\min} - P_i \right) \right] \right| \quad (1)$$

where a_i, b_i and c_i are quadratic cost coefficients, e_i and f_i are non-linear cost coefficients due to valve point effect, P_i^{\min} and P_i^{\max} are the minimum and maximum power output limit of the i th unit generating, P_i is the power output of i th unit and N is the number of the committed generators.

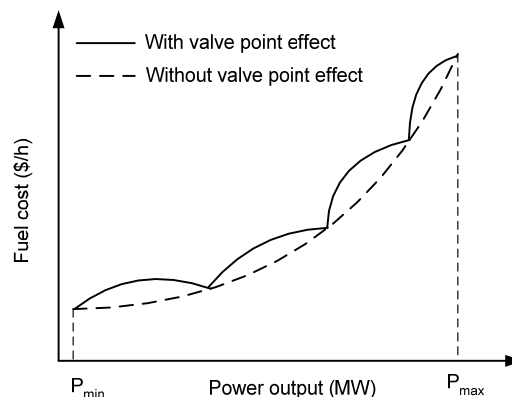


Figure 1. Cost and Power Output Relationship with and without VPE

2.2. Constraints

The minimization of F_c in (1) is subjected to the system and operational constraints as follows:

2.2.1. Power Balance Constraint

The total power produced by the scheduled generator must meet the total power demand (P_D) and transmission loss (P_{Loss}) as follows:

$$\sum_{i=1}^N P_i - P_D - P_{Loss} \tag{2}$$

The P_{Loss} can be calculated by Kron's loss formula as follows:

$$P_{Loss} = \sum_{i=1}^N \sum_{j=1}^N P_i(t) B_{ij} P_j(t) + \sum_{i=1}^N B_{0i} P_i(t) + B_{00} \tag{3}$$

where B_{ij} , B_0 and B_{00} are the loss coefficients obtained from the power flow calculation.

2.2.2. Power Output Limits

For stable operation, the real power produced by each generator must be within allowable minimum (P_i^{min}) and maximum P_i^{max}) limits as follows:

$$P_i^{min} \leq P_i \leq P_i^{max} \tag{4}$$

3. PROPOSED GBEST ARTIFICIAL BEE COLONY (GABC) FOR OED

Artificial Bee Colony (ABC) is a population based algorithm inspired by behaviour of honey bees colonies for finding food sources. It consists of three main bees in order to search optimal food source (solution) which are employed bees, onlooker bees and scout bees. The brief working principle of ABC as follows[19]:

Artificial Bee Colony Algorithm

Step 1 Initialization

Determine the number of food source (SN)

Calculate vector of possible solution $X_i = X_1, X_2, \dots, X_{SN}$; X_i is represent by the location of food source.

The fitness of each possible solution can be calculate using the following formula:

$$Fitness_i = \begin{cases} \frac{1}{1 + F_i}, & \text{if } F_i \geq 0 \\ 1 + abs(F_i), & \text{otherwise} \end{cases} \tag{5}$$

Step 2 Employed Bees

Employed Bees find the new food source position V_{ij} using:

$$V_{ij} = X_{ij} + \phi_{ij} * (X_{ij} - X_{kj}) \tag{6}$$

where ϕ_{ij} is a random number between [-1, 1], and $k \in \{1, 2, \dots, N_s\}$ and $j \in \{1, 2, \dots, D\}$ are index randomly chosen. D is number of problem variables.

If the new position is found better than the old position, a new position is memorized and otherwise it is removed. The greedy selection method is used to determine the best solution.

Step 3 Onlooker Bees

In this phase, onlooker bees will search the best results according to the probability (P_i) as follows:

$$P_i = \left\{ \frac{Fitness_i}{\sum_j^{N_s} Fitness_j} \right. \quad (7)$$

The solution with better fitness value has high probability of being selected by an onlooker bee in order to exploit the solution near to global optimal value.

Step 4 Scout Bees

After several trials, unimproved food location (solution) will explore other possible location in order to improve the current solution using the following equation:

$$X_{ij} = X_j^{\min} + rand[0,1] * (X_j^{\max} - X_j^{\min}) \quad (8)$$

The good position replaced the unimproved solution.

Repeat **Steps 2 – 4** until satisfied the stopping criteria

The details working principle of ACB algorithm can be found in [20] [11].

3.1. Working Principle of GABC

To improve the exploitation capability of ABC, the global best solution (gbest) in PSO algorithm [21] is used to update the solution in ABC. Therefore, Gbest Artificial Bee Colony (GABC) modified solution in (6) as follows [16]:

$$V_{ij} = X_{ij} + \phi_{ij} * (X_{ij} - X_{kj}) + \Psi_{ij} * (gbest_j - X_{ij}) \quad (9)$$

where Ψ_{ij} is an uniform random number in $[0, C]$, where C is a non-negative constant and $gbest_j$ represents the j th element of the gbest vector.

3.2. Implementation Procedures of GABC for Solving OED Problem

The details implementation of GABC algorithm for solving OED problem is described as follows:

GABC for Solving OED Problem

- Step 1** Input data: Cost and system data.
- Step 2** Parameter setting for GABC. The number of generator is defined as problem variables.
- Step 3** Calculate the fitness value in (5) according to objective function in (1). Set the iteration equal to 1.
- Step 4** Employed bees determine new candidate food source based on (9).
- Step 5** Apply the constraints handling in order to satisfy the constraints in (2)–(4). The details of constraints handling methodology can be found in [22].
- Step 6** Calculate the fitness value.
If the new fitness value is better than the old one, the new food source position is remembered; otherwise, the old one is remain in the memory.
- Step 7** Onlooker bees determine the better solution using (7).
- Step 8** Apply greedy selection process and store the best solution.
- Step 9** Scout bee produces a new random solution according to (8) for unimproved solution after certain limits.
- Step 10** Store the best solution (food source position) obtained so far and increase iteration number by 1.
- Step 11** Repeat Steps 4 to 10 until maximum number of cycles are reached.

4. RESULTS AND ANALYSIS

The proposed GABC algorithm has been tested on two Case Studies by using Matlab 2013b software in order to validate its performances. The IEEE 14-bus 5unit generators and IEEE-30 bus 6 unit generators test system are considered in this paper. To evaluate the robustness of GABC, 40 different trials are conducted and compared with ABC algorithm. The optimal power output are also compared with the selected published results.

4.1. Test Case 1: IEEE 14-Bus 5 Unit Generators

The GABC and ABC algorithms have been used to determine the OED for IEEE 14 bus 5-unit generator considering VPE and transmission losses. The total load demand (P_D) is 259 MW. The system and operational data are taken from [23]. The optimal power output produced by GABC and ABC are tabulated in Table 1. It shows that proposed GABC can obtained lower cost as well as significant cost reduction compared to ABC algorithm around 3.6 \$/h. Moreover, searching behaviour of GABC is also faster than ABC as shown in Figure 2. It can be seen the GABC has capability to find minimum cost with 100 iterations that highlighted the effectiveness of GABC algorithm.

In term of consistency, it found that GABC can give minimum cost for every trial as presented in Figure 3. It can be seen that GABC has capability to obtained lower cost with good solution. The results obtained from the GABC algorithm has been compared with those reported results by GA [23], GA_APO [23], NSOA [23], PSO [24], MSG_HP [24], PSOGSA [7] and ABC as presented in Figure 4. It is can be seen that proposed GABC can provide lower cost as compared to other algorithms. Thus, it can give significant cost saving for solving OED problem.

Table 1. Optimal Power Output by ABC and GABC Algorithm (Test Case 1)

Generator unit	ABC	GABC
P ₁	199.5996	199.5997
P ₂	20.0000	20.0000
P ₃	20.97576	21.08906
P ₄	15.51043	15.48928
P ₅	12.46985	12.37705
Total power output (MW)	268.5556	268.5550
P_{Loss} (MW)	9.5556	9.5550
Fuel cost (\$/h)	834.13	830.53

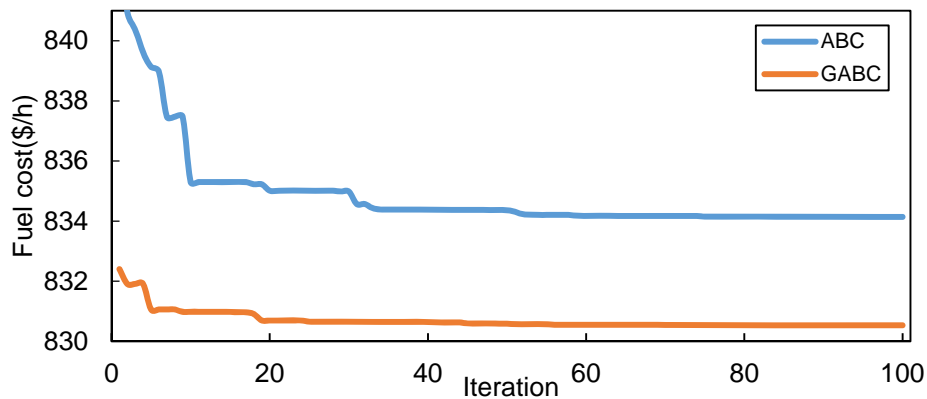


Figure 2. Convergence Characteristic of ABC and GABC Algorithm for Test Case 1

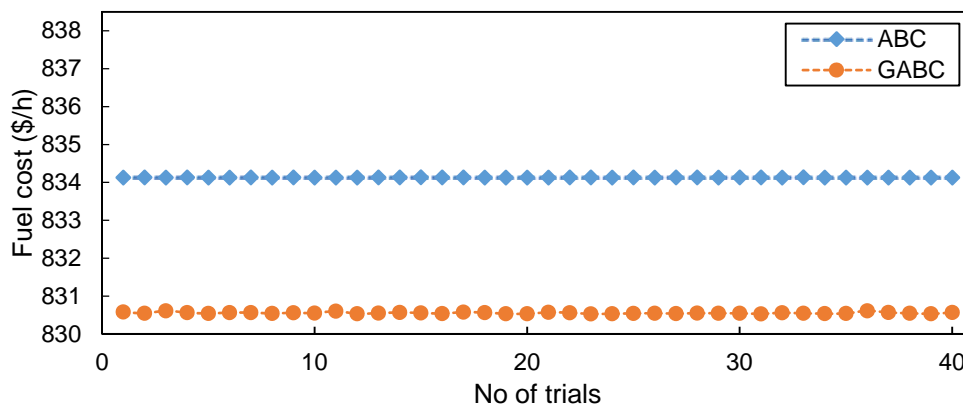


Figure 3. Robustness of ABC and GABC Algorithm for Test Case 1

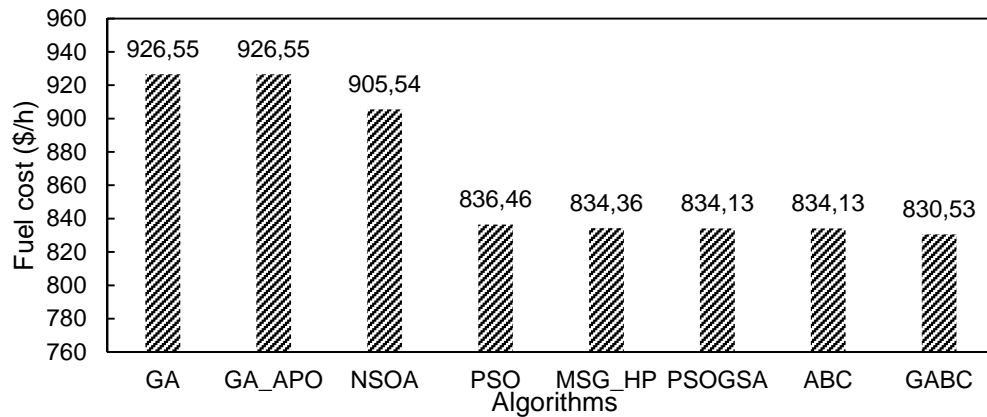


Figure 4. Comparison of Optimal Cost of GABC and Other Algorithms (Test Case 1)

4.2. Test Case 2: IEEE 30 Bus 6-Unit Generators

The GABC and ABC algorithms have been tested on the IEEE 30-bus 6 unit generators with VPE and transmission losses. The power demand of this system is 283.4 MW. The system and operational data are obtained from [23]. After 40 different runs, the best results obtained by GABC and ABC are shown in Table 2. The GABC can provide a better cost as compared to ABC with reduction of 0.43 \$/h. However, the convergence behaviour of GABC algorithm is faster than ABC for finding optimal cost within 100 iterations as shown in Figure 5. The minimum results after 40 different runs are presented in Figure 6 highlighted the effectiveness of GABC for obtaining lower cost and consistent results compared to ABC.

To validate the performance of proposed GABC for solving OED problem, the comparison study has been made with the reported results of GA [23], GA_APO [23], NSOA [23], PSO [24], MSG_HP [24], PSOGSA [7] and ABC as shown in Figure 7. It clearly shows that proposed GABC obtained better results compared to the selected algorithms. Thus, it can give a good potential cost saving for optimal power generation.

Table 2. Optimal Power Output by ABC and GABC Algorithm (Test Case 2)

Generator unit	ABC	GABC
P ₁	199.5996	199.5996
P ₂	20.0000	20.0000
P ₃	23.9788	23.9552
P ₄	18.8220	18.8559
P ₅	18.2319	18.1714
P ₆	13.8711	13.8113
Total power output (MW)	294.5034	294.3934
P_{Loss} (MW)	11.1034	10.9934
Fuel cost (\$/h)	925.41	924.98

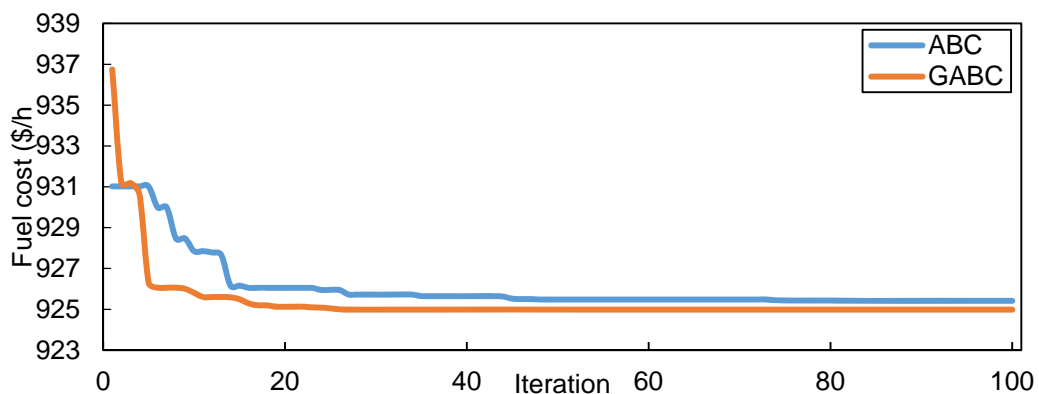


Figure 5. Convergence Characteristic of ABC and GABC Algorithm for Test Case 2

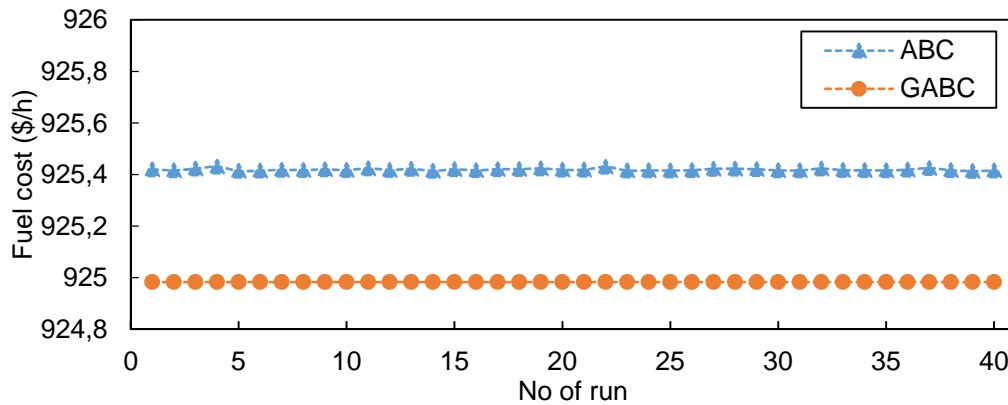


Figure 6. Robustness of ABC and GABC Algorithm for Test Case 2

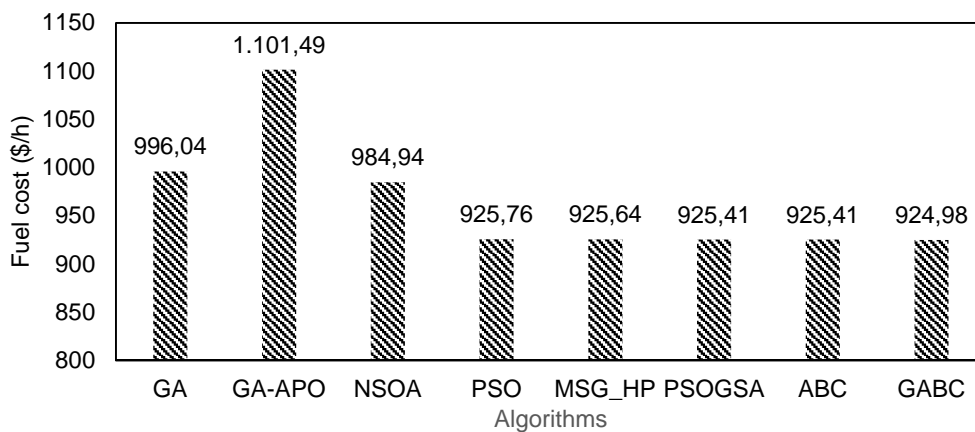


Figure 7. Comparison of Optimal Cost of GABC and Other Algorithms (Test Case 2)

5. CONCLUSION

The Gbest Artificial Bee Colony (GABC) algorithm has been proposed for solving the OED problem with valve point effect. The OED problem with non-convex cost function are difficult to obtain the optimal solution by most of reported results of heuristic algorithm. Therefore, this paper investigated the effectiveness of proposed GABC to solve this problem based on the two different case studies which are IEEE 14-bus 5 unit generators and IEEE 30-bus 6 unit generators considering valve point effect and transmission losses. The comparison study has been conducted in terms of optimal cost, convergence characteristic and robustness. It found that GABC provided a significant cost reduction as well as good convergence behavior as compared to ABC. Moreover, the optimal OED solution obtained by GABC is outperformed compared to selected results reported in literature. From this study, it can be concluded that GABC has good potential to be implemented in other power system optimization problems especially in optimal power dispatch area.

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