Economic dispatch problem using artificial bee colony optimization based on predator and prey concept

Abstract. These Artificial bee colony (ABC) algorithm is one of the most recent nature-inspired based algorithms, which has been shown to be competitive to other population-based algorithms. However, there is still an insufficiency in ABC regarding its solution search equation, which is good at exploration but poor at exploitation. In this paper, which combines the ABC algorithm and predator-prey (PP) methodology, the PP procedure was incorporated into the ABC algorithm to enhance the process of exploitation. Application of ABC algorithm combined with PP is based on mathematical modelling to solve Economic Dispatch (ED) problems. This combination is tested on 6-Units system. Simulation results are compared with those of other studies reported in the literature, and the comparative results demonstrate our proposed method is more feasible and effective. This method can be deemed to be a promising alternative for solving the (ED) problems in real systems.

Keywords: Economic Dispatch, metaheuristic optimization, artificial bee colony algorithm, predator-prey approach.

Introduction
Economic dispatch (ED) problem is allocating loads to plants for minimum cost while meeting the constraints. It is formulated as an optimization problem of minimizing the total fuel cost of all committed plant while meeting the demand and losses. Previous efforts on solving ED problems have employed various mathematical programming methods and optimization techniques. These conventional methods include the lambda-iteration method and the gradient method [1]. In these numerical methods, an essential assumption is that the incremental cost curves of the units are monotonically increasing piecewise-linear functions. The gradient method which it is relies on an initial guess of solution. This may lead to divergence or produce local minimum solution which leads to undesirable pattern.

In recent years, Nature-Inspired Computing (NIC) becomes more and more attractive for the researchers. The algorithms in NIC are often applied to solve problems of optimization. It can be defined as the measure, which introduces the collective behavior of social insect colonies, other animal societies or the relationship description of unsophisticated agents interacting with their environment, to design algorithms or distributed problem-solving devices.

NIC studies the collective behaviour of systems composed of many individuals interacting locally with each other and with their environment. In order to make numerical methods more convenient for solving ED problems, the recent research has focused on the metaheuristics approaches such as Ant Colony Optimization (ACO) [2], Particle Swarm Optimization (PSO) [3, 4], Artificial Bee Colony (ABC) [5].

It has also been shown that these algorithms have been successfully employed to solve ED problems for units with piecewise quadratic fuel cost functions and can provide better solutions in comparison to classical algorithms.

Artificial bee colony (ABC) algorithm was recently proposed by Karaboga in 2005 [6, 7]. The basic idea of designing ABC is to mimic the foraging behavior (such as exploration, exploitation, recruitment and abandonment) of honeybees. Since the invention of the ABC algorithm, it has been used to solve both numerical and no numerical optimization problems. The performance of ABC algorithm has been compared with some other intelligent algorithms, such as GA [8], differential evolution algorithm (DE) [9], the simulation results demonstrated that the ABC algorithm has the capability of getting out of a local minimum trap which make it a promising candidate in dealing with multivariable, multimodal function optimization tasks. Recently, for improving the performance of ABC algorithm, many variant ABC algorithms have been developed.

In this paper, the ABC algorithm is applied to solve ED problems with a new design concept based on predator-prey optimization. Integrating the ABC algorithm into predator-prey optimization in order to improve its capability of finding satisfactory solutions and increasing the diversity of the population. Simulation results of the ABC algorithm and ABC-PP approaches are compared with others optimization approaches presented in recent literature.

The rest of this paper is organized as follows: Section 2 presents the problem formulation. The original ABC algorithm is introduced in section 3. Afterward, the section 4 presents the basic concept of PP and the proposed ABC-PP algorithm. Furthermore, the section 5 shows the results and presents discussions. The conclusion and future work are summarized in section 6.

Problem Formulation
The ED problem is to find the optimal combination of power generations that minimizes the total generation cost while satisfying an equality constraint and inequality constraints. The variants of the problems are numerous which model the objective and the constraints in different ways. The basic economic dispatch problem can be described mathematically as minimization of problem for
minimizing the total fuel cost of all committed plants subject to the constraints.

(1) \( \text{Minimize } \sum_{i=1}^{n} F_i(P_i) \)

\( F_i(P_i) \) is the fuel cost equation of the \( i \)th plant. It is the variation of fuel cost ($ or Rs) with generated power (MW). Normally it is expressed as continuous quadratic equation.

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

The power generated \( P_i \) by each generator shall be within their lower limit \( P_{i,\text{min}} \) and upper limit \( P_{i,\text{max}} \). So that

(3) \( P_{i,\text{min}} \leq P_i \leq P_{i,\text{max}} \)

While minimizing the total generation cost, the total generation \( P_t \) should meet the total demand \( P_d \) and transmission network loss \( P_L \).

(4) \( P_t = \sum_{i=1}^{n} P_i = P_d + P_L \)

The transmission loss can be determined form either \( B_{\text{max}} \) or power flow.

(5) \( P_L = \sum_{i=1}^{n} P_i B_{ij} P_j \)

For better convergence, chose a plant which has maximum capacity and range. It is considered as plant \( 1 \). The reference plant allocation is fixed by the equations (4-5).

Convert the constrained optimization problem as an unconstrained problem by penalty function method.

(6) \( \text{Minimize } \sum_{i=1}^{n} F_i(P_i) + 1000 \times \text{abs} \left( \sum_{i=1}^{n} P_i - P_d + P_L \right) \)

Artificial Bee Colony (ABC) algorithm

The artificial bee colony (ABC) algorithm was designed for numerical optimization problems and it was inspired by the foraging behavior of honey bees [7, 10].

The main advantages of the ABC algorithm are derived from the fact that the algorithm uses only three (03) control parameters: colony size, maximum cycle number and limit. ABC algorithm consists of two groups of bees: employed artificial bees (i.e., current exploiting foragers) and unemployed artificial bees (i.e., looking for a food source to exploit). The latter will be classified further in two groups: the onlooker bees and the scout bees. The employed bees will be randomly sent to the food sources and evaluating the onlooker bees and the scout bees. The employed bees exploit). The latter will be classified further in two groups: employed bees (i.e., current exploiting foragers) and unemployed artificial bees (i.e., looking for a food source to exploit). The initial population can be defined as \( P(G)=0 \) of \( SN \) solutions (food source positions), where \( SN \) denotes the size of employed bees or onlooker bees. Moreover, each solution \( x_{ij} (i=1, 2, ..., SN; j=1, 2, ..., D) \) is a \( D \)-dimensional vector. Here, \( D \) is the number of optimization parameters.

Then, placing the employed bees on the food sources in the memory and updating feasible food source. In order to produce a candidate food position from the old one \( (x_{ij}) \) in the memory, the employed bees is updated via equation (7) [10].

(7) \( v_{ij} = x_{ij} + \phi_{ij} (x_{ij} - x_{jk}) \)

where \( v_{ij} \) is a new feasible dimension value of the food sources that is modified from its previous food sources value \( x_{ij} \) based on a comparison with the randomly selected neighboring food source value \( x_{ij} \), and \( \phi_{ij} \) is a random number between \([-1, 1] \) to adjust the production of neighbor food sources around \( x_{ij} \) and represents the comparison of two food positions visually.

An artificial onlooker bee chooses a food source depending on the probability value associated with that food source, \( p_i \) is calculated by the following equation (8):

(8) \( p_i = \frac{\text{fit}_i}{\sum_{j=1}^{SN} \text{fit}_j} \)

where \( \text{fit}_i \) is the fitness value of the solution \( i \) which is proportional to the nectar amount of the food source in the position \( i \) and \( SN \) is the number of food sources which is equal to the number of employed bees or onlooker bees.

The value of \( \text{fit}_i \) for the \( i \)th employed bee can be calculated by equation (9) below:

(9) \( \text{fit}_i = \begin{cases} \frac{1}{1 + f_i} & \text{if } ( f_i \geq 0 ) \\ 1 + \text{abs} ( f_i ) & \text{if } ( f_i < 0 ) \end{cases} \)

The value of predetermined number of cycles is an important control parameter of the ABC algorithm, which is called ‘limit’ for abandonment. Assume that the abandoned source is \( x_j \) and \( j \in [1, 2, ..., D] \), then the scout discovers a new food source to be replaced with \( x_j \). This operation can be defined as in equation (10):

(10) \( x_{ij} = x_{min} + \text{rand} [0,1] (x_{max} - x_{min}) \)

where \( x_{min} \) and \( x_{max} \) are the lower and upper limit respectively of the search scope on each dimension.

After each candidate source position \( v_{ij} \) is produced and then evaluated by the artificial bee, its performance is compared with that of its old one. If the new food source has equal or better nectar than the old source, it is replaced with the old one in the memory.
The main steps of the ABC algorithm are given below:

- **Initialize.**
- **Repeat.**
  - (a) Place the employed bees on the food sources in the memory;
  - (b) Place the onlooker bees on the food sources in the memory;
  - (c) Send the scouts to the search area for discovering new food sources.
- **Until** (requirements are met).

**Artificial Bee Colony (ABC) based on Predator-Prey (ABC-PP)**

The first idea of the Predator-Prey method is to introduce diversity in the search of the optimization. There is a continuous tussle between predators and their prey. Predator species need to be adapted for efficient hunting if they are to catch enough food to survive. Prey species, on the other hand, must be well adapted to escape their predators, if enough of them are to survive for the species to continue. The predators help to control the prey population while creating pressure in the prey population.

In this model, an individual element in prey-predator population represents a solution. Each prey in the population can expand or get killed by predators based on its fitness value, and a predator always tries to kill preys with least fitness in its surroundings, which represents removing (local) of bad solutions and preserving (local) good solutions in the population. In this paper, the concept of predator-prey is used to increase the diversity of the population, and the predators are modeled based on the best solutions which are given as follows [11]:

\[
(PP)_{\text{predator}} = (PP)_{\text{best}} + \rho \left(1 - \frac{\text{Iter}}{\text{Iter}_{\text{max}}} \right)
\]

(11)

Where \((PP)_{\text{predator}}\) is a possible solution in the population, \((PP)_{\text{best}}\) is the best solution in the population, \(\rho\) is the hunting rate of the predator, \(\text{Iter}\) is the current iteration and \(\text{Iter}_{\text{max}}\) is the maximum number of iterations.

If the predator influences the prey and the interactions between predator and prey provide the solutions to maintain a distance \(d\) from the predator, then an exponential term will also be included as given by:

\[
(PP)_{k+1} = \begin{cases} 
(PP)_k + \rho e^{-|d|} & d > 0 \\
(PP)_k - \rho e^{-|d|} & d < 0 
\end{cases}
\]

(12)

where \(k\) is the current iteration.

The last ABC-PP operator is inspired from the predator and prey model to ensure diversification of food sources features. This is motivated by the fact that, in nature, bees try to find good nectar flowers and in the same time, avoid its predators [11,12].

In optimization, the closest food source (preys) will roll away from the best solution (predator) to explore other search space's parts.

The scout phase will be replaced by a \(PP\) model to imitate natural process where foraging bees gather nectar from optimal sources while trying to avoid their predators. A predator in turn tries to hunt bees in good food sources. In this case, the \(PP\) will ensure diversification and avoids local optima.

The ABC-PP starts by initializing the algorithm parameters: the number of decision variables \(D\), their ranges, bees number \(SN\), maximum cycle's number \(\text{Iter}_{\text{max}}\) and defines the appropriate objective function. After that, the start food sources are generated randomly [11].

The algorithm of the search process using ABC-PP can be outlined by the following general scheme in Fig. 1.

**Simulation Results**

To assess the efficiency of the proposed ABC-PP, it has been applied to ED problems with 6-Units IEEE 30-bus system. Total power demand \(P_d = 700\) (MW).

The results obtained from the ABC-PP are compared with those of other methods: Quadratic Programming (QP) [2], Simulated Annealing (SA) [13], Differential Evolution (DE) [9], Particle Swarm Optimization (PSO) [4], Genetic Algorithm (GA) [8], Bat Algorithm (BA) [14,15] and ABC [5].

The programs for all methods are written in MATLAB software package. The cost coefficients and generating capacity limits of 6-Units system are given in table1.

<table>
<thead>
<tr>
<th>Unit</th>
<th>(a) ($/MW·h)</th>
<th>(b) ($/MWh)</th>
<th>(c) ($/h)</th>
<th>(P_{\text{min}}) (MW)</th>
<th>(P_{\text{max}}) (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.0033870</td>
<td>0.856440</td>
<td>16.817750</td>
<td>10</td>
<td>125</td>
</tr>
<tr>
<td>2</td>
<td>0.0023500</td>
<td>1.025760</td>
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<td>10</td>
<td>150</td>
</tr>
<tr>
<td>3</td>
<td>0.0006230</td>
<td>0.897700</td>
<td>23.33280</td>
<td>35</td>
<td>225</td>
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<tr>
<td>4</td>
<td>0.0007880</td>
<td>0.851234</td>
<td>27.63400</td>
<td>35</td>
<td>210</td>
</tr>
<tr>
<td>5</td>
<td>0.0004690</td>
<td>0.807285</td>
<td>36.85680</td>
<td>35</td>
<td>325</td>
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<td>6</td>
<td>0.0003998</td>
<td>0.850454</td>
<td>30.14790</td>
<td>35</td>
<td>315</td>
</tr>
</tbody>
</table>

Table 1. Fuel cost coefficients and generation limits of 6-Units IEEE 30-bus system.

The loss coefficient matrix of 6-Units system is:

\[
B_{\text{loss}} = \begin{bmatrix}
0.000140 & 0.000017 & 0.000015 & 0.000019 & 0.000026 & 0.000022 \\
0.000017 & 0.000060 & 0.000013 & 0.000016 & 0.000015 & 0.000020 \\
0.000015 & 0.000013 & 0.000065 & 0.000017 & 0.000024 & 0.000019 \\
0.000019 & 0.000016 & 0.000017 & 0.000071 & 0.000030 & 0.000025 \\
0.000026 & 0.000015 & 0.000024 & 0.000030 & 0.000069 & 0.000032 \\
0.000022 & 0.000020 & 0.000019 & 0.000025 & 0.000032 & 0.000083
\end{bmatrix}
\]

Table 2 shows the results obtained by applying the proposed algorithm were compared to those obtained by QP, SA, DE, PSO, GA, BA and ABC. The comparison shows that BA performs better than the mentioned methods.
When compared with BA, the proposed method shows that the total fuel cost and transmission network loss are decreased significantly. Therefore, the ABC-PP optimization has superior features, including quality of solution, stable convergence characteristics and good computational efficiency. It is a promising technique for solving complicated problems in power system.

Table 2. The simulation results for 6-Units IEEE30-bus system

<table>
<thead>
<tr>
<th>Unit</th>
<th>QP (MW)</th>
<th>SA (MW)</th>
<th>DE (MW)</th>
<th>PSO (MW)</th>
<th>GA (MW)</th>
<th>BA (MW)</th>
<th>ABC (MW)</th>
<th>ABC-PP (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>P2</td>
<td>10.0000</td>
<td>10.0000</td>
<td>10.0000</td>
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<td>10.0442</td>
<td>10.0000</td>
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<td>P3</td>
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<td>118.9328</td>
<td>118.936</td>
<td>119.2947</td>
<td>119.3956</td>
<td>119.0983</td>
<td>119.7598</td>
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<tr>
<td>P4</td>
<td>118.6697</td>
<td>118.6713</td>
<td>118.6697</td>
<td>118.6732</td>
<td>118.7149</td>
<td>118.6984</td>
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<tr>
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<td>212.9494</td>
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<tr>
<td>P7</td>
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<td>719.4322</td>
<td>719.4322</td>
<td>719.4321</td>
<td>719.4280</td>
<td>719.4208</td>
<td>719.4119</td>
<td>719.4012</td>
</tr>
<tr>
<td>Cost ($/h)</td>
<td>820.2665</td>
<td>820.2665</td>
<td>820.2665</td>
<td>820.2660</td>
<td>820.2670</td>
<td>820.2664</td>
<td>820.2664</td>
<td>820.2663</td>
</tr>
</tbody>
</table>

Conclusion

In this paper, a hybrid ABC algorithm based on PP approach (ABC-PP) was presented. We adopted PP procedure for the scout bees. Original ABC suffers from slow convergence and unbalanced trade-off between exploitation and exploration. By introducing PP method into ABC, we overcame this deficiency. The simulation results so obtained are compared to that of recent approaches reported in the literature. The comparison shows that BA performs better than the mentioned methods. Therefore, the proposed ABC-PP method can be a very favorable method for solving the non-convex ED problem.

As for the main direction of our future work with the PP approach, it will probably lead to the development a multi-predator sub-population version of the algorithm.

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