1. Naima HASSANI[1], 2. Hamid BOUZEBOUDJA[2], 3. Mimoun YOUNES[1]

University of Sidi Bel Abbes, Algeria (1),
University of Sciences and Technology of Oran, Algeria (2)

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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.*

Streszczenie.** Algorytm sztucznej kolonii pszczół (ABC) jest jednym z najnowszych algorytmów inspirowanych naturą, który, jak wykazano, jest konkurencyjny w stosunku do innych algorytmów populacyjnych. Jednak w ABC nadal brakuje równania wyszukiwania rozwiązań, które jest dobre w eksploracji, ale słabe w eksploatacji. W tym artykule, który łączy algorytm ABC i metodologię drapieżnik-ofiara (PP), procedura PP została włączona do algorytmu ABC w celu usprawnienia procesu eksploatacji. Zastosowanie algorytmu ABC w połączeniu z PP opiera się na modelowaniu matematycznym do rozwiązywania problemów Ekonomicznej Dyspozycji (ED). Ta kombinacja jest testowana w systemie 6-jednostkowym. Wyniki symulacji są porównywane z wynikami innych badań opisanych w literaturze, a wyniki porównawcze pokazują, że proponowana przez nas metoda jest bardziej wykonalna i skuteczna. Metoda ta może być uznana za obiecującą alternatywę rozwiązywania problemów (ED) w rzeczywistych systemach.* (Rozwiązywanie problemu ekonomicznej wysyłki za pomocą sztucznej optymalizacji kolonii pszczół w oparciu o koncepcję drapieżnika i zdobycz***)

Keywords: Economic Dispatch, metaheuristic optimization, artificial bee colony algorithm, predator-prey approach.
Słowa kluczowe: ekonomiczny rozsył energii, algorytm rpojowy.

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

$F_i\ (P_i)$ 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 $P_{i,min}$ and upper limit $P_{i,max}$. So that

(3) $$P_{i,min} \le P_i \le P_{i,max}$$

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_{mn} coefficients or power flow.

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

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) $$Minimize \sum_{i=1}^{n} F_i(P_i) + 1000 * abs(\sum_{i=1}^{n} P_i - P_d + P_L)$$

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 their nectar amounts. If an employed bee finds a better solution, she will update her memory; otherwise, she counts the number of the searches around the source in her memory. If all employed bees complete the search process, the nectar and position information of the food sources will be shared with the onlooker bees. An onlooker bee does not have any source in her memory and thus she will evaluate all the information from employed bees and choose a probably profitable food source (recruitment).

After arriving at the selected area, the onlooker bee searches the neighborhood of the source and if she finds a better solution, she will update the food source position just as an employed bee does.

The criterion for determination of a new food source is based on the comparison process of food source positions visually. Stopping the exploitation process of the sources abandoned by the employed/onlooker bees if the new solution cannot be further improved through a predetermined number of trials limit. At this moment, the employed/onlooker bees become scout bees. Sending the scouts into the search area for discovering new food sources (exploration). Thus, in the ABC algorithm onlooker and employed bees are responsible for the exploitation process, while scouts take care of the exploration. In ABC algorithm, each food source represents a feasible solution of the optimization problem and the nectar amount of a food source is evaluated by the fitness value (quality) of the associated solution. The number of employed bees is set to that of food sources.

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 memory, the memory by employed bees is updated via equation (7) [10].

(7) $$v_{ij} = x_{ij} + \phi_{ij}(x_{ij} - x_{kj}), \quad j \in \{1,2,\ldots,D\}, k \in \{1,2,\ldots,SN\} \wedge k \ne i$$

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_{kj}), and (ϕ_{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) $$p_i = \frac{fit_i}{\sum_{n=1}^{SN} fit_n}$$

where 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 fit_i for the *'i'th* employed bee can be calculated by equation (9) below:

(9) $$fit_i = \begin{cases} \dfrac{1}{1+f_i} & if\ (f_i \ge 0) \\ 1 + abs(f_i) & if\ (f_i < 0) \end{cases}$$

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 $j \in \{1, 2,\ldots, D\}$, then the scout discovers a new food source to be replaced with x_i. This operation can be defined as in equation (10):

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

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]:

$$(PP)_{predator} = (PP)_{best} + \rho\left(1 - \frac{Iter}{Iter_{max}}\right) \quad (11)$$

Where $(PP)_{predator}$ is a possible solution in the population, $(PP)_{best}$ is the best solution in the population, ρ is the hunting rate of the predator, $Iter$ is the current iteration and $Iter_{max}$ 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:

$$\begin{cases} (PP)_{k+1} = (PP)_k + \rho e^{-|d|} & d > 0 \\ (PP)_{k+1} = (PP)_k - \rho e^{-|d|} & d < 0 \end{cases} \quad (12)$$

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 $Iter_{max}$ 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.

Initialize SN, $Iter_{max}$, ρ.
Initialize start food sources.
While $Iter < Iter_{max}$
    For Each employed bee i
        Calculate f_i; and fit_i.
        Create new source v_{ij} and apply greedy selection.
    EndFor
    For Each onlooker i
        Compute probability P_i.
        Select source using P_i
        Create new source v_{ij} and apply greedy selection.
    EndFor
        Assign predator to best source using (11).
    For Each employed bee i
        Compute distance d and Update the bee position (12).
    EndFor
EndWhile

Fig.1. ABC-PP algorithm

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

Unit	a ($\$/MW^2h$)	b ($/MWh)	c ($/h)	P_{min} (MW)	P_{max} (MW)
1	0.0033870	0.856440	16.817750	10	125
2	0.0023500	1.025760	10.029450	10	150
3	0.0006230	0.897700	23.333280	35	225
4	0.0007880	0.851234	27.634000	35	210
5	0.0004690	0.807285	36.856880	130	325
6	0.0003998	0.850454	30.147980	125	315

The loss coefficient matrix of 6-Units system is:

$$B_{6x6} = \begin{bmatrix} 0.000140 & 0.000017 & 0.000015 & 0.000019 & 0.000026 & 0.000022 \\ 0.000017 & 0.000060 & 0.000013 & 0.000016 & 0.000015 & 0.000020 \\ 0.000015 & 0.000013 & 0.000065 & 0.000017 & 0.000024 & 0.000019 \\ 0.000019 & 0.000016 & 0.000017 & 0.000071 & 0.000030 & 0.000025 \\ 0.000026 & 0.000015 & 0.000024 & 0.000030 & 0.000069 & 0.000032 \\ 0.000022 & 0.000020 & 0.000019 & 0.000025 & 0.000032 & 0.000085 \end{bmatrix}$$

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

Unit	QP	SA	DE	PSO	GA	**BA**	ABC	**ABC-PP**
P_1 (MW)	28.2992	28.2952	28.2992	28.2963	28.3564	28.3291	28.3187	28.2442
P_2 (MW)	10.0000	10.0003	10.0000	10.0000	10.0442	10.0000	10.0001	10.0000
P_3 (MW)	118.9327	118.9389	118.9328	118.9386	118.9247	119.3956	119.0983	119.7598
P_4 (MW)	118.6697	118.6713	118.6697	118.6732	118.7149	118.6984	118.6618	119.1434
P_5 (MW)	230.8055	230.7898	230.8054	230.8005	230.8933	230.6757	230.9377	232.1736
P_6 (MW)	212.7252	212.7368	212.7251	212.7235	212.4945	212.3210	212.4109	210.0801
P_T (MW)	719.4322	719.4322	719.4322	719.4321	719.4280	**719.4199**	719.4273	**719.4012**
Cost ($/h)	820.2665	820.2665	820.2665	820.2665	820.2670	**820.2664**	820.2666	**820.2663**
P_L (MW)	19.4322	19.4322	19.4322	19.4321	19.4280	**19.4199**	19.4273	**19.4012**

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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***Authors**: HASSANI Naima, IRECOM Laboratory (Team "New Energy and Artificial Intelligence"), phd student at Electrical Engineering Department, Faculty of Electrical Engineering, BP 89 Djillali Liabes University of Sidi Bel Abbes 22000, Algeria. E-mail: naimahassani69@yahoo.fr*

Dr. Mimoun YOUNES, ICEPS Laboratory, Faculty sciences of Engineering Djillali Liabes University of Sidi Bel Abbes 22000, Algeria.E-mail: younesmi@yahoo.fr

Dr. Hamid BOUZEBOUDJA, University of Sciences and Technology of Oran, Algeria, E-mail:hbouzeboudja@yahoo.fr

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