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Application of Economic Load Dispatch to Power Systems with the Artificial Bee Colony Algorithm Approach

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Abstract: The economic dispatch problem has received increasing attention with the development of modern power systems. It is an optimization problem that aims to find the most economical schedule of generating units while satisfying load demand and operational constraints. In this paper, the application of the Artificial Bee Colony (ABC) algorithm to the economic dispatch problem is presented. The proposed method is demonstrated using a six-unit system. Additionally, the results obtained from the proposed method are compared with those from other optimization methods applied to the same problem.

Yapay Arı Kolonisi Algoritması Yaklaşımı ile Ekonomik Yük Dağıtımının Güç Sistemlerine Uygulanması

Anahtar Kelimeler
Ekonomik yük dağıtımı,
Güç sistemleri,
Optimizasyon

Öz: Modern güç sistemlerindeki gelişmelerle birlikte ekonomik yük dağıtımı araştırmacıların ilgisini çekmeye başlamıştır. Ekonomik yük dağıtımı ise yük talebi ve diğer işletme kısıtlarını sağlama koşulları altında üretim üniteleri arasında en ekonomik dağıtımı yapan bir optimizasyon problemidir. Bu çalışmada kayıpları olan iletim hattı şebekesini besleyen 6 üniteli sistemin optimum çalışma noktaları Yapay Arı Kolonisi (YAK) algoritması yardımıyla belirlenmiştir. Elde edilen sonuçlar aynı problemin farklı optimizasyon problemleri sonuçlarıyla karşılaştırılmıştır.

1. INTRODUCTION

With the increase in industrialization and the development of technology, the need for energy is increasing day by day. Moreover, the spread of urbanization and the acceleration of migration from villages to cities have increased energy usage in daily life. In fact, Turkey's national energy plan envisages a 39.5% increase in primary energy consumption in 2035 compared to 2020 [1]. This situation creates an additional burden for countries to meet the demand. Therefore, the efficient use of the energy produced, the reduction of losses, and energy consumption with minimum cost have become crucial issues.

Since Economic Load Dispatch (ELD) is made to dispatch the energy demanded by consumers among generators with the lowest possible cost, finding a solution to this problem has strategic importance for the power system. Therefore, ELD conditions can be met by minimizing generation and transmission costs. The power generation cost function is obtained by combining fuel, idle, and start-up costs. When minimizing the fuel costs of generators in power systems, it is desired to produce power at the most appropriate value between the maximum and minimum values. Recently, heuristic methods, which are reliable, fast, and effective optimization algorithms, have been used as an alternative to the mathematical approaches used in solving the Economic Dispatch (ED) problem [2].

Bouzeboudja et al. solved the economic dispatch problem in IEEE's 25 busbar system by using a real coded genetic algorithm with different methods [3]. Abido dealt with the environmental/economic dispatch problem with the genetic algorithm, pareto genetic algorithm and pareto evolution algorithm in nonlinear optimization solutions in IEEE's 30 busbar system [4]. Türkay examined the ELD problem with a genetic algorithm to feed generators at minimum cost [5]. Alrashidi and El-Hawary solved the environmental/economic dispatch problem of particle swarm optimization in IEEE's 30 busbar power system and compared the results with different methods [6]. Wang and Singh [7] studied the ED problem in a four-zone power system. It is used a modified particle swarm optimization algorithm, taking into account environmental effects in IEEE's 30-bus power system. Bouktir et al. investigated the environmental and economic load dispatch problem using the multi-particle swarm optimization algorithm. Vishwakarma et al. have studied the solution to the ELD problem by using Simulation Annealing Algorithm [8]. Cai et al. [9] solved the ED problem using the chaotic ant swarm optimization algorithm.

Ozyon et al. addressed the environmental power dispatch problem on an IEEE 6 generator 30 busbar test system. The multi-objective optimization problem was transformed into a single-objective optimization problem with the weighting process, and its solution was provided by the Artificial Bee Colony (ABC) algorithm. The results were examined by evaluating whether losses were included or not on the test system [10].

Öztürk et al. have realized an ELD problem that minimizes the energy cost for the load provided by a three-unit thermal power plant with the ABC algorithm. The results showed that the ABC algorithm produces economic results in determining the output power of the generator units [11].

Eminoğlu and Karahan developed an interface to solve the ELD problem in their study. Through this interface, the study solved the ELD problem with Differential Improvement Algorithm (DGA) and Particle Swarm Optimization (PSO) and compared the performances of the algorithms. The results revealed that the PSO algorithm performs better in the ELD problem [12].

Özyon discussed the environmental and economic load dispatch problem by adding wind and solar energy generation resources to the thermal power plants in the IEEE 30-bus-6 generator power system. The optimization results of the system were obtained by using the Charged System Search (CSS) algorithm, including both renewable energy sources and only thermal power [13]. Andic et al. solved the ELD problem with the Crow Search Algorithm (CAA) by incorporating the valve point effects of steam turbines. However, it is emphasized that the solution they developed was more successful compared with Genetic Algorithm (GA) and Symbiotic Organisms Search (SOS) [14].

Dixit et al. examined the generation system consisting of 18 thermal units with a second-order (Convex) cost function, a standard IEEE 30 bus system, and 15 power generation units with emission restrictions in the island of Crete the ABC method they proposed. They compared the obtained results with different algorithms and revealed that the ABC method is easy to integrate, has fast convergence, and has a high ability to perform searches close to the optimum solution [15].

Turgut and Demir addressed the ELD problem by applying Artificial Cooperative Search (ACS) to two different test power generation systems. They showed lower operating costs with LFS compared to other algorithms [16].

Özyön investigated the effects of wind power plants on the ELD problem using DGA. The results were compared with other studies in the literature, which was carried out on two separate test systems by considering and neglecting the transmission losses [17].

ABC is an algorithm with very few control parameters based on swarm intelligence, which can be used for solving numerical and discrete problems. In this study, the ELD problem, one of the optimization problems, is solved using the heuristic method ABC. The problem is based on the data of the study conducted in Turkey. The obtained results are compared with the results of different optimization problems of the same problem. In this study, it has been seen that heuristic methods give more reliable and better results than traditional methods and can successfully solve the economic dispatch problem in a power system used in Turkey. Furthermore, the proposed method is applied to a system with six generators, and the results are obtained and compared with the results obtained from other available studies. As a result, it has been shown how the ABC algorithm and program can be successfully applied in solving the economic load dispatch problem.

2. MATERIAL AND METHOD

The solution to the ELD problem involves operating the generators in power systems within specific limit values in response to increasing load demand while minimizing the overall system cost. The economic dispatch aims to determine the optimal allocation for each unit at intervals of 3 to 5 minutes based on the load requirements [2]. Figure 1 depicts the connection diagram of thermal power plants on a transmission line in relation to the load demand.

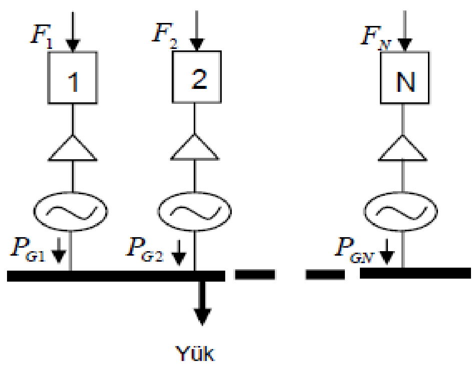

Figure 1. Connection diagram of thermal power plants to the transmission line

The ELD problem in energy systems is a power allocation problem characterized by large-scale linear and nonlinear constraints. The input of the fossil fuel generator is defined as a function of the output power, which can be represented by linear, piecewise, exponential, or polynomial functions. In this study, the input-output characteristic is modeled using a quadratic equation. The objective of ELD is to minimize the operating cost of the entire group of generators. Mathematically, the operating cost of the total generators can be expressed as follows.

$$Min \sum_{i=1}^{N} F_i(P_i) = Min \sum_{i=1}^{N} a_i + b_i P_i + c_i P_i^2 \tag{1}$$

The objective function (cost function) given by Equation 1 is solved depending on the following constraints. The output power of the generators must be greater than or equal to the minimum active power value or less than or equal to the maximum active power value within the limit values determined as shown in Equation 2.
Power balance constraint :

$$\sum_{i=1}^{N} P_i - P_D - P_L = 0 \tag{2}$$

Here, the loss of the transmission line is found as follows.

$$P_L = \sum_{i=1}^{N} B_i - P_i^2 \tag{3}$$

Output power capacity of generators: The generator's output power must be greater than or equal to the minimum allowable power value or less than or equal to the maximum allowable power value.

$$P_{min,i} \leq P_i \leq P_{max,i} \tag{4}$$

The cost function of the ED problem, as indicated in Equation 1, serves as the objective function in ABC and chaotic ABC (CABC). The variables utilized in the objective function are assigned randomly within the limit values specified in Equation 2. Equation 3 represents the total active power loss of the transmission line, while Equation 4 presents the active power balance equation of the transmission line. In ED problems, the constraints described in Equations 3 and 4 are also taken into account and employed as penalty functions in ABC and CABC.

$$P_L = \sum_{i=1}^{N} \sum_{j=1}^{N} PiBijPj + \sum_{i=1}^{N} Bi0Pi + B_{00} \tag{5}$$

$$D = \sum_{i=1}^{N} P_{Gi} - P_D - P_L = 0 \tag{6}$$

In the above equations:
P_{Gi} : Output power of the i^th generator
a_i, b_i, c_i : Price coefficients of the i^th generator
$F_i(P_{Gi})$: The price required for the generator to produce P_i power
N : Number of groups
P_{Gi}^{min} : Minimum output power of i^th generator
P_{Gi}^{max} : Maximum output power of the i^th generator
P_L : Loss of transmission line
B_{ij} : Transmission line loss coefficient matrix
B_{0i} : The vector of the same length as P
B_{00} : Constant
P_D : The demanded power

3. ARTIFICIAL BEE COLONY ALGORITHM (ABC)

ABC was initially developed by Derviş Karaboğa in 2005 as an optimization algorithm based on the behavior of bee colonies for real parameter optimization [18]. In a bee colony's natural life, there is a division of tasks among bees collecting honey. Worker bees, observer bees, and scout bees carry out distinct roles within the colony. Worker bees are responsible for visiting honey sources, collecting flower essences, and depositing the honey they gather into the hive. Additionally, worker bees have the task of communicating the quality of the honey source they collect to the observer bees. Observer bees, in turn, identify new honey sources and guide the worker bees towards them. To identify new sources, observer bees rely on the previous observations made by worker bees, which are then analyzed. Scout bees, on the other hand, wander randomly and search for new honey sources solely based on their own observations. In the algorithm, the process of determining the address of the nectar source is presented as a solution to the optimization problem. The size of the nectar source is considered as the degree of suitability in the relevant solution. According to the algorithm, each honey source is collected by a single worker bee, thus the number of solutions in the population is equal to the number of employed bees [18].

The algorithm operates through the following five fundamental steps:
1. Determining the initial values of honey source regions,
2. Directing the worker bees to the designated honey sources,
3. Conducting probability calculations for candidate regions that could become honey sources,
4. Observer bees determining new honey sources based on the information conveyed by the worker bees,
5. Decision-making regarding decommissioning existing honey sources.

In the algorithm, the initial values of the honey source regions are assigned using Equation 7 [18].

$$x_{ij} = x_j^{min} + rand(0,1)(x_j^{max} - x_j^{min}) \quad (7)$$

In the equation, j represents the number of produced resources, while i represents the number of optimization parameters.

During the second step, the worker bee gathers nectar from the designated honey source. Additionally, it assesses the quality of a new source by analyzing a nearby honey source. The calculation for the exploration of the new honey source is provided in Equation 8, where ϕ is a random real number within the range of [-1, 1] [18].

$$v_{ij} = x_{ij} + \phi_{ij}(x_{ij} - x_{kj}) \quad (8)$$

If the value of ij v exceeds the pre-defined parameter limits during the evaluation process, the translation is performed based on Equation 9. Subsequently, the suitability of the solution cost is calculated using Equation 10 [18].

$$v_{ij} = \begin{cases} x_j^{min}, & v_{ij} < x_j^{min} \\ v_{ij}, & x_j^{min} \le v_{ij} \le x_j^{max} \\ x_j^{max}, & v_{ij} > x_j^{max} \end{cases} \quad (9)$$

$$fitness_i = \begin{cases} 1/(1+f_i, & f_i \ge 0 \\ 1 + abs(f_i), & f_i < 0 \end{cases} \quad (10)$$

The observer bees evaluate the cost/availability ratios of the hive, and a probability-based selection is made based on the amount of nectar. In the basic ABC algorithm, the roulette wheel method is used for probability-based selection. Consequently, the size of each slice depends on the fitness value it represents. The final stage of the algorithm involves determining the depleted honey source. After completing the search process of the worker and observer bees, the algorithm can identify a honey source that has been depleted. Counters that are updated during the search process are utilized for this purpose. If the counter for any honey source exceeds the control parameter, referred to as the limit and determined by the algorithm, that particular source is deemed exhausted and abandoned. As a result, the worker bee associated with the abandoned region is removed from the algorithm. The scout bee that discovers a new source transform into a worker bee, collecting honey from the newfound source, and the limit value for that source is reset. Only one scout bee is allowed to emerge per cycle. There are two criteria for terminating the algorithm. These conditions can be defined as either reaching the maximum number of cycles or exceeding a specified fault tolerance value, as determined by the user [18].

4. APPLICATION OF ABC ALGORITHM TO ELD SYSTEM

When searching for a solution to an optimization problem, general optimization techniques are employed to minimize or maximize objective functions based on available data. In the case of a classical economic load dispatch problem, the objective is to achieve maximum power output at the lowest cost while maintaining power balance. However, traditional optimization methods may not be adequate for solving such problems. Therefore, in this article, the economic load dispatch problem is addressed using the ABC method. The ABC algorithm, known for its minimal control parameters and reliance on swarm intelligence, can effectively tackle numerical and discrete problems. The economic load dispatch problem is implemented using the ABC method in the Matlab environment, and the problem-solving process is depicted in Figure 2, illustrating the flow diagram designed for this purpose.

The algorithm begins by creating a random colony with a size determined by the number of variables and bees. Half of the colony consists of worker bees, while the other half represents observer bees. Worker bees select random sources, calculate their positions, and store them in temporary memory. In each cycle, a worker bee discards the data in its memory if it achieves better results in the subsequent cycle, retaining only the best result. Nectar amounts are calculated by the bees based on the best source positions, and these amounts are stored in memory throughout the cycles, with the best solution determined at the end of the maximum cycle.

Observer bees visit sources and calculate nectar amounts based on information received from the worker bees. Worker bees, in search of better nectar around a selected source, visit neighboring sources up to a defined limit and compare the nectar amounts. If a newly found source is superior, the worker bee discards the previous nectar amount and considers the new source as the center for the next cycle. If no improvement is found, one of the worker bees becomes a scout bee and searches for a new source.

This study addresses the economic load dispatch problem using the ABC method. A test system with 6 generators is employed to evaluate the proposed method's performance. The obtained results are compared with those from different methods. The details and limitations of the test system can be found in Table 1.

Table 1. The data and limitations of the test system

Unit	A	B	C	Pmin	Pmax
1	0.007	7	240	100	500
2	0.0095	10	200	50	200
3	0.0090	8.5	220	80	300
4	0.0090	11	200	50	150
5	0.0080	10.5	220	50	200
6	0.0075	12	190	50	120

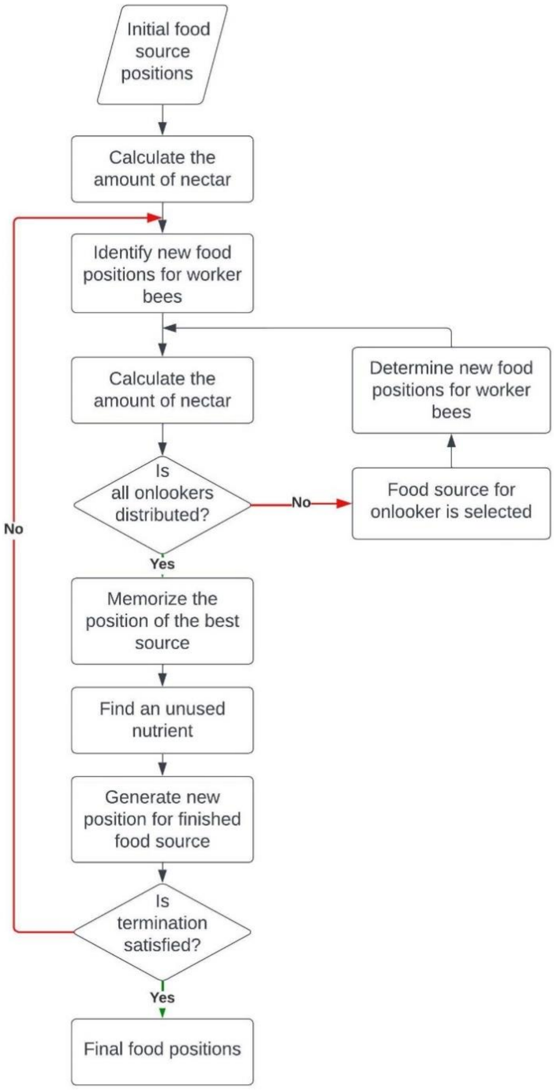

Figure 2. Flow diagram of ABC algorithm for ELD problem

The program worked in 1001 steps; the objective value was found to be 15445.9011. The output power values to be produced for each generator are presented in Table 2.

Table 2. The output power for each generator

Generator	ABC	CABC
Pg_1	444.1615	441.7425
Pg_2	162.0570	180.9894
Pg_3	258.2421	257.4831
Pg_4	150.0000	149.9746
Pg_5	175.7886	159.3187
Pg_6	85.1814	85.68010
Total loss	12.4250	12.1885
Total cost	15453.0979	15445.9011

The Chaotic Artificial Bee Colony (CABC) algorithm utilizes chaotic maps in comparison to the traditional Artificial Bee Colony (ABC) algorithm, providing several advantages such as enhanced convergence speed, improved solution distribution, sensitivity to initial values, and adaptability. The utilization of chaotic maps based on chaos theory equips the CABC algorithm with stronger search and exploration capabilities. Chaos theory focuses on randomness and irregularity in dynamic systems, allowing for better dispersion of solutions. This enables the algorithm to approach global optima more swiftly and effectively. Additionally, the impact of chaotic maps facilitates faster convergence and aids in solving complex problems more expeditiously in CABC. The sensitivity to initial values allows CABC to yield better results in a shorter time, enhancing its responsiveness to initial conditions. Furthermore, its adaptability enables the algorithm to perform better in specific problems and may prove more effective for diverse types of optimization problems.

Considering factors such as problem size, complexity, computational power, and initial values in the context of the addressed ELD problem, it is evident that the results obtained through the CABC algorithm are more successful compared to those achieved using ABC.

5. DISCUSSION AND CONCLUSION

To solve the ELD problem using the ABC algorithm, multiple attempts were made within the algorithm, and the best result obtained was considered as the solution for the ELD problem. The ABC algorithm was executed multiple times until the stopping criterion was satisfied, and the values that yielded the optimal solution were recorded as the final result. In this study, the number of cycles was adopted as the stopping criterion. By running the algorithm "i" times, it was observed that the desired result could be achieved within approximately "n" cycles. To ensure reliability, a total of 1001 cycles were selected.

The CABC algorithm, through the utilization of chaotic maps based on chaos theory, exhibits improved convergence speed, better solution distribution, sensitivity to initial values, and adaptability. As demonstrated in Table 2, these capabilities enable the algorithm to yield more successful cost function responses and lower loss values.

In future works, the integration of renewable energy resources into the existing thermal power units will be explored, and the impact of renewable energy sources on the system's operation will be investigated.

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