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Solving the Economic Dispatch by Artificial Bees Colony (ABC) Algorithm

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حل مشكلة الإرسال الاقتصادي باستخدام خوارزمية مستعمرة النحل الاصطناعية

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Abstract:
The goal of Economic Dispatch (ED), a basic optimization problem in power system operation, is to ascertain the ideal power output of producing units while satisfying system restrictions and minimizing overall fuel costs. Nonlinearity, nonconvex cost functions, and intricate operational restrictions like power balancing and generator limits are common challenges for conventional optimization techniques. This study applies the Artificial Bees Colony (ABC) algorithm, a swarm intelligence-based metaheuristic inspired by honey bee foraging behavior, to effectively solve the Economic Dispatch problem. In order to effectively handle nonlinear and limited optimization problems, the ABC algorithm uses employed bees, observer bees, and scout bees to explore and exploit the search space.
The proposed approach is implemented on a practical power system model consisting of three thermal generating units selected from the Libyan electrical network, namely Misurata, Al-Khums, and West Tripoli power plants. Simulation results demonstrate that the ABC algorithm successfully determines the optimal generation schedule while satisfying power balance and generator operating limits.

Keywords: Economic Dispatch, Artificial Bees Colony (ABC) algorithm, optimization problem

الملخص
يهدف الإرسال الاقتصادي، باعتباره إحدى المشكلات الأساسية في تحسين تشغيل أنظمة القدرة الكهربائية، إلى تحديد القيم المثلى لقدرة التوليد لوحدات الإنتاج مع الالتزام بقيود النظام المختلفة وتحقيق أقل تكلفة كلية للوقود. وتواجه تقنيات التحسين التقليدية تحديات عديدة عند معالجة هذه المشكلة، نظرًا لوجود اللاخطية، ودوال التكلفة غير المحدبة، إضافة إلى القيود التشغيلية المعقدة مثل توازن القدرة وحدود تشغيل المولدات. في هذه الدراسة، تم تطبيق خوارزمية مستعمرة النحل الاصطناعية، وهي خوارزمية ميتا-استدلالية قائمة على الذكاء السربي ومُستوحاة من سلوك البحث عن الغذاء لدى أسراب نحل العسل، لحل مشكلة الإرسال الاقتصادي بكفاءة. تعتمد خوارزمية ABC على ثلاث فئات من النحل، وهي النحل العامل،

والنحل المراقب، ونحل الكشافة، من أجل استكشاف فضاء البحث واستغلال الحلول الواعدة بفاعلية، مما يجعلها مناسبة لمعالجة مشكلات التحسين اللاخطية والمقيدة.
تم تطبيق المنهجية المقترحة على نموذج عملي لنظام قدرة كهربائية يتكون من ثلاث وحدات توليد حرارية مختارة من الشبكة الكهربائية الليبية، وهي محطات مصراته والخمس وغرب طرابلس. وقد أظهرت نتائج المحاكاة أن خوارزمية ABC قادرة على تحديد جدول التوليد الأمثل بنجاح، مع تحقيق توازن القدرة والالتزام بحدود التشغيل الخاصة بوحدات التوليد.

الكلمات المفتاحية: التوزيع الاقتصادي، خوارزمية مستعمرة النحل الاصطناعية، مشكلة التحسين

Introduction

In Libya, the primary sources of power generation consist of gas-fired and oil-fired methods. With the continuous rise in global prices of gas and oil, it has become crucial to minimize the operational expenses of electrical energy. Presently, there is a growing public awareness regarding environmental issues. Engineers now bear the responsibility of reducing pollution, conserving various fuel sources, and minimizing costs to protect the environment

Optimal power distribution serves as an essential tool for network managers to ascertain the optimal conditions for safe and cost-effective operation of the electrical energy system. By utilizing mathematical programming techniques, the Optimal Power Distribution process enables the determination of the most suitable configuration of system control parameters while meeting specific operational and safety criteria. Economic dispatch, also known as the allocation of the economic load, is a specific instance of the broader concept of optimal power distribution. [1]

Economic load dispatch is a process used to determine the amount of electrical power that should be generated by the committed generating units within a power system, with the goal of minimizing the total system cost while meeting the required load demand. It involves the allocation of generation levels among various generating units to ensure that the system's load demand is satisfied in the most cost-effective manner [2]. Economic dispatch refers to the real-time allocation of load among generating units operating in parallel with the system. The main objective is to minimize the overall cost of meeting the system's moment-to-moment energy demands [3].

Hence, the essence of economic dispatch lies in harmonizing the production expenses across all power plants within the system, and this serves as the primary focus of the project. [4]

Several classic optimization techniques have been extensively studied, including linear programming (LP), homogeneous linear programming (HLP), nonlinear programming (NLP), quadratic programming (QP), and dynamic programming (DP). While these methods provide effective approaches to solving optimization problems, their application is fully functional only under specific conditions. In Artificial Bees Colony (ABC) Algorithm, which falls into a distinct category, differs from strict mathematical methods by demonstrating an inherent ability to adapt to nonlinear, non-convex, and discontinuous problems. This adaptability has made AI-based approaches increasingly popular for addressing optimization challenges, particularly in the field of ED [5].

In this paper, the Artificial Bee Colony (ABC) algorithm is proposed to solve ED problem. The ABC algorithm is a new meta-heuristic approach inspired by the intelligent foraging behavior of honey-bee swarm.

Literature Review

Economic Dispatch (ED) problem as a one of the most crucial issues in power system optimization has been studied thoroughly, since it directly leads to operational cost and efficiency in system. The application of intelligent optimization techniques in ED has remarkably developed during the last years leading to the solution of EDP with nonlinear, non-smooth and multi-constraint nature. This section presents a literature survey on (1) ABC in power system optimization and (2) other intelligent algorithms in solving ED problem, including PSO, GA, FA. A comparative review of their advantages and drawbacks is further provided.

Studies Using the ABC Algorithm in Power System Optimization

The proposed algorithm is applied to different non-convex ED problems. Four different test systems consisting 6, 10, 15, and 20 generating units are used to validate the consistency of the proposed algorithm to detect the optimal solution for a given objective. Their foundational work demonstrated the algorithms capability to solve complex numerical optimization problems effectively [5]. Applied ABC for the solution to ED problem and conclude that this method has a better performance (low fuel cost) and faster convergence compared to traditional technique [6]. Likewise, ABC were applied to the ED with valve-point loading effects, whose consequences are not smooth and very non-linear form of cost function. Their works indicated that ABC generated steady and precise solutions which outperformed PSO in such intricate instances [7]. utilized ABC to optimize hybrid renewable energy system, which has indicated good performance in solving multi-objective and multiple constraints problems. The work has drawn attention to ABC as a powerful and versatile mechanism for larger-size and mixed-energy systems [8].

Studies on Economic Dispatch Using Intelligent Optimization Techniques.

Economic Dispatch (ED) is one of the most significant optimization problems in power systems operation. The primary goal is to schedule the power output of committed generating units, such that the total fuel cost of all units and total unfilled demand are minimized while respecting system operation constraints including power balance constrains and generator limits [9].

Genetic Algorithm (GA) is one of the earliest and most extensively used intelligent computing techniques inspired by natural selection, genetic evolution. The proposed method carries out better than GA for the Economic Dispatch problems with non-smooth and discontinuous fuel cost functions. Several researchers have shown that GA can deal with non-linear constraints efficiently and near-global optimal solution for higher dimensional problems however its convergence rate and efficiency may depend on parameters like population size, mutation rate among others [10].

Another well-known intelligent optimization approach is PSO which considered the social behaviour of bird flockings and fish underwater. In problems of ED, PSO draws much attention for its easy construction, rapid convergence and simple implementation. Many comparative studies have demonstrated that PSO provides higher solution quality and convergence speed than conventional methods and a GA, in particular for large-scale power systems [11] [12].

Other IOT algorithms used for ED are Ant Colony Optimization (ACO), Differential Evolution (DE), Simulated Annealing (SA), Harmony Search(HS) [13]– [16]. It has been interesting, in recent years to propose hybrid optimization based on two (or more) intelligent methods, hybrids. Hybrid approaches aim to capitalize on the two algorithms' advantages, and they have shown better convergence speed, higher precision, and more robustness for complex ED scenarios [17].

Research Method

This paper discusses the research methodology followed to solve the ELD problem with ABC algorithm. The mathematical statement of the ELD problem, that is, objective function and operational constraints, is firstly provided. Then, the fundamental principles and implementation steps of the ABC algorithm are described, highlighting its suitability for solving non-linear and constrained optimization problems such as economic dispatch.

Economic Load Dispatch Formulation

Economic load dispatch (ELD) problem is a fundamental optimization problem in power system operation. Its primary aim is to determine the best power output of each generating unit in order to reach the minimization of total fuel cost of generation that meets the system load demand and operational constraints.

Objective Function

In this study, the fuel cost characteristic of each generating unit is represented by a quadratic function of the active power output. The total generation cost is expressed as:

$$\min C_{total} = \sum_{i=1}^{N} C_i\,(P_i) \qquad (1)$$

where
N is the number of generating units,

P_i is the real power output of unit i(MW),
$Ci(Pi)$is the fuel cost function of unit iii, which is given by:

$$Ci(Pi) = a_i P_i^2 + b_i P_i + c_i \quad (2)$$

Where

a_i,b_i and c_i are the cost coefficients of the i-th generating unit.

Power Balance Constraint

The total generated power must meet the system load demand, which is mathematically expressed as:

$$\sum_{i=1}^{N} P_i = P_D \quad (3)$$

where P_D is the total load demand of the system (MW). Transmission losses are neglected in this study for simplicity.

Generator Operating Constraints

Each generating unit must operate within its specified minimum and maximum power limits:

$$P_{i,min} \leq P_I \leq P_{i,max} \ , \quad (i = 1, 2, \dots \dots .., N) \quad (4)$$

where, $P_{i,min}$ represents the minimum real power as signed at unit i and $P_{i,max}$ represents the maximum real power assigned at unit i.

Artificial Bee Colony (ABC) Algorithm

The ABC algorithm is proposed by Karaboga in 2005 [18], The Artificial Bee Colony (ABC) algorithm is one of popular metaheuristic optimization methods motivated by the natural foraging phenomena of honey bees in nature. Because the ABC algorithm is simple and rough, but possesses powerful global search capacity, it has been used to solve numerous (complex) non-linear optimization problems in recent years such as Economic Load Dispatch problem.

In ABC, the colony contains three kinds of bees: employed bee, onlooker bee and scout bee. Food sources are the potential solutions of the optimization problem and nectar amount denosites the fitness value of solution. The process of the ABC algorithm is presented as follows:

Initialization Phase

Initially, a set of food sources is randomly generated within the feasible limits of the decision variables:

$$x_{ij} = x_j^{min} + \text{rand}(0,1)(x_j^{max} - x_j^{min}) \quad (5)$$

where rand (0,1) is a uniformly distributed random number between 0 and 1.

Employed Bee Phase

Each employed bee searches for a new solution in the neighborhood of its current food source using the following equation:

$$v_{ij} = x_{ij} + \emptyset_{ij}(x_{ij} - x_{kj}) \quad (6)$$

where
x_{ij} is the current solution,

x_{kj} is a randomly selected solution $k = i$.
$\emptyset_{ij}$ is a random number in the range [−1,1].

If the new solution yields a better fitness value, it replaces the previous one.

Onlooker Bee Phase

Onlooker bees select food sources based on a probability proportional to their fitness values. Better solutions have a higher chance of being selected, enhancing exploitation of promising regions in the search space. The probability value that a food source will be selected is calculated by the following expression:

$$v_{ij} = \begin{cases} x_j^{min} & , \quad v_{ij} < x_j^{min} \\ v_{ij} & , \quad x_j^{min} \leq v_{ij} \leq x_j^{max} \\ x_j^{max} & , \quad v_{ij} < x_j^{max} \end{cases} \tag{7}$$

$$fitness_i = \begin{cases} \frac{1}{1+f_i} & if \quad f_i \geq 0 \\ 1 + f_i & if \quad f_i < 0 \end{cases} \tag{8}$$

where Fi is the value of objective function.

Scout Bee Phase

If a food source cannot be improved after a predefined number of trials, it is abandoned, and the corresponding employed bee becomes a scout bee. A new food source is then randomly generated to replace the abandoned one, ensuring diversity and preventing premature convergence.

Termination Criterion

The ABC algorithm iteratively executes the above phases until a maximum number of iterations is reached or convergence is achieved. The best solution obtained represents the optimal generation schedule that minimizes the total fuel cost while satisfying all ELD constraints

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Results and discussion

In this section, we provide and discuss the results obtained from solving the ELD problem based on ABC algorithm. The main purpose is to validate the efficiency, and convergence performance of the proposed ABC defense star ego through application to practical power system case study based on the Libyan electrical network.

To maintain realism and practical significance, three thermal generation units of the Libyan power system were considered. These plants are large power plants serving the western region of Libya and were selected because operational data, fuel consumption data and because of their high contribution to system generation. The chosen plants are the Misurata, Al-Khums, and West Tripoli. The quadratic fuel cost function is employed for each generating unit.

The next equations are the source units at Misurata, Al-Khums, and West Tripoli PP in Libyan power system. These cost functions were derived from the corresponding fuel consumption characteristics character is tics and were transformed to equivalent expressions in Dr/h for each cost function, thus defining the objective functions of ED problem, as well as the mathematical model over which ABC is employed.

In study [1], the fuel consumption curve of the generating unit was represented as a quadratic relationship between the active power output P[MW]and the thermal fuel input rate $H(P)$ [MBtu/h], expressed as follows:

$$\mathrm{H(P) = 0.0076P2 + 8.167P + 91.061[MBtu/h]}$$

$$\mathrm{H(P) = 0.0079P2 + 8.1223P + 92.058[MBtu/h]}$$

$$\mathrm{H(P) = 0.0058P2 + 8.7834P + 153.43[MBtu/h]}$$

By using the higher heating value of heavy fuel,

$$\mathrm{HV} = 39.5\ \mathrm{MBtu/m^3},$$

and the gas price,

$$C_f = 38\ Dr/\mathrm{m^3}$$

Step 1: Conversion of Fuel Price to Dr/MBtu

The fuel price is first converted from Dr/m³ to Dr /MBtu using the higher heating value

$$\text{Fuel price per MBtu} = \frac{38}{39.5} = 0.962025\ [\mathrm{Dr/MBtu}]$$

Step 2: Multiplication of the Heat Rate Equation by the Fuel Price

The fuel cost function is obtained by multiplying the heat rate equation by the fuel price per MBtu

$$C(P) = 0.00731P^2 + 7.8569P + 87.603 \quad [\mathrm{Dr}/h]$$

$$C(P) = 0.007605P^2 + 7.815P + 88.58 \quad [\mathrm{Dr}/h]$$

$$C(P) = 0.005580P^2 + 8.450P + 147.64 \quad [\mathrm{Dr}/h]$$

The electric power system to be simulated is composed of three thermal generating units taken from the Libyan electricity network. The system load request is observed for two typical levels with 180MW, 230MW and, which present different operating conditions. The cost coefficients for each generating unit are listed in Table 1.

Table 1 Cost Coefficients of 3-Unit System

Unit	**a**	**b**	**c**	P_{min}	P_{max}
1	0.0076	7.8569	87.603	40	110
2	0.007605	7.815	88.58	40	110
3	0.005580	8.450	147.64	50	105

The ABC algorithm has been used to solve the ED problem of a power system consisting of three generating units. The method was used to solve power generation optimum for each unit under system load demand and operating limitations. The best generation results are displayed and listed in Table 2.

Table 2 Cost Coefficients of 3-Unit System

Unit power output	Power Demand (MW)
	180
P1	67.19
P2	69.34
P3	43.47
Optimal Cost (Dr/h)	1842.36

The total output power is 180.00 MW and equal to the system load demand, which verifies that the power balance constraint is indeed satisfied. Its minimum total fuel cost obtained is 1842.36 Dr/h. These results reveal that the

ABC algorithm can effectively distribute the load between the generating units based on their cost functions, thus benefiting those with lower incremental costs and taking into consideration of their operating limits.

The convergence behavior of the ABC is described in Fig 1 (ABC Convergence Curve). It can be seen that the cost of fuel essentially decreases in the beginning few iterations quickly, revealing an efficient global exploration capacity. Within a few iterations the solution converges continuously to a stable minimum value of 1842.36 Dr/h.

This convergence behaviour reveals the stability and rapid convergence characteristics of ABC algorithm towards ED. The lack of excessive oscillations in the latter iterations shows that there is stable exploitation around the solution.

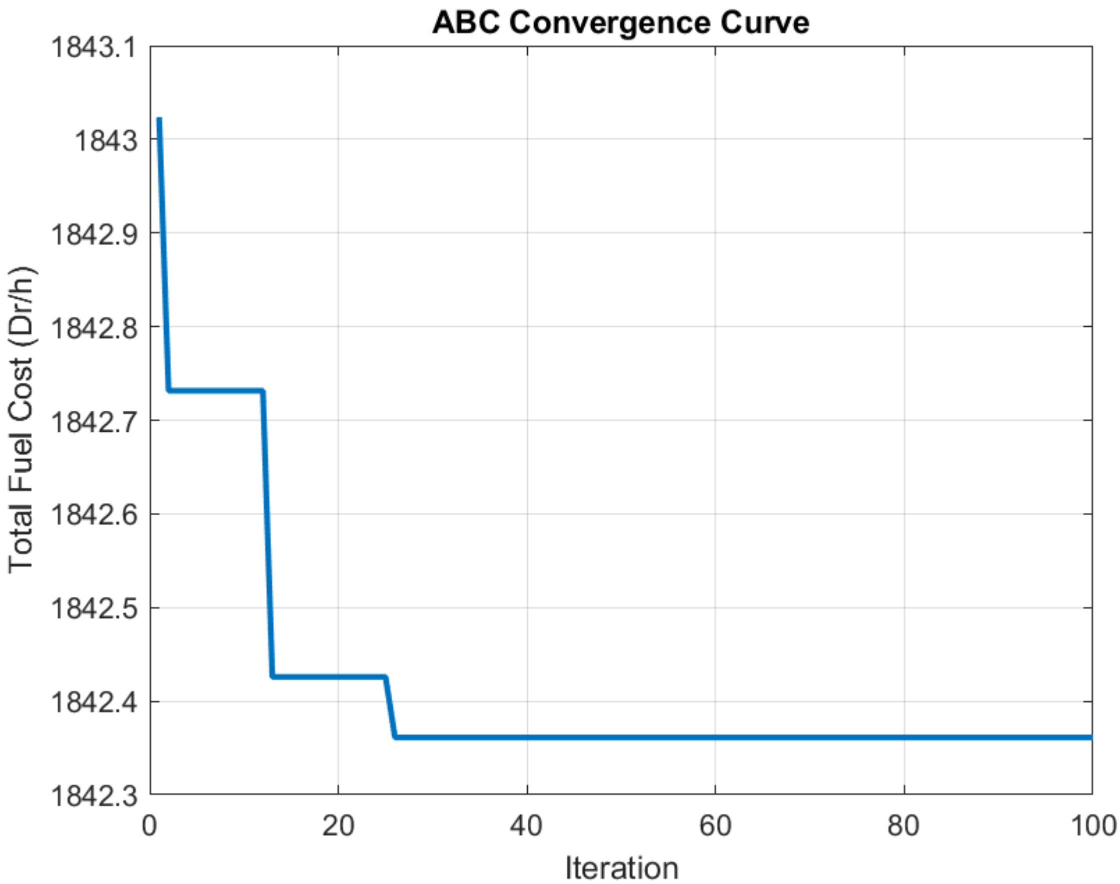

Figure 1: ABC Convergence Curve

In Fig. 2, optimal active power production of each generating unit is shown by bar graph, using ABC technique. It can be seen that Generators 1 and 2 contribute more to the demand than Generator 3. This is in accordance to their respective fuel cost coefficients, because the algorithm provides higher generation levels for units with better cost characteristics.

The obtained results validate that ABC method is able to distinguish generators with their cost functions and provides optimal operation of generation.

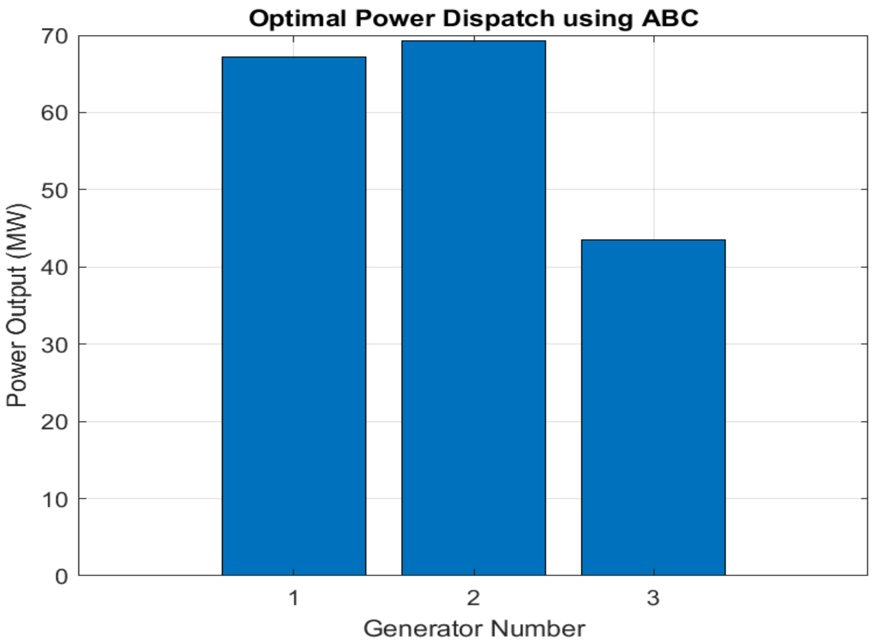

Figure 2: Optimal Power Dispatch using ABC

The quadratics fuel cost curves of the 3 generating units are plotted in Figure 3. It can be observed that along the power output and fuel cost relationship is not linear. The identification of different slopes in the curves indicates that the incremental costs differ between generators. The optimal operating points obtained from the ABC algorithm lie on these curves in a manner that ensures minimum total cost while maintaining system constraints. This verifies the applicability of quadratic cost function and the ABC algorithm to solve non-linear objective functions.

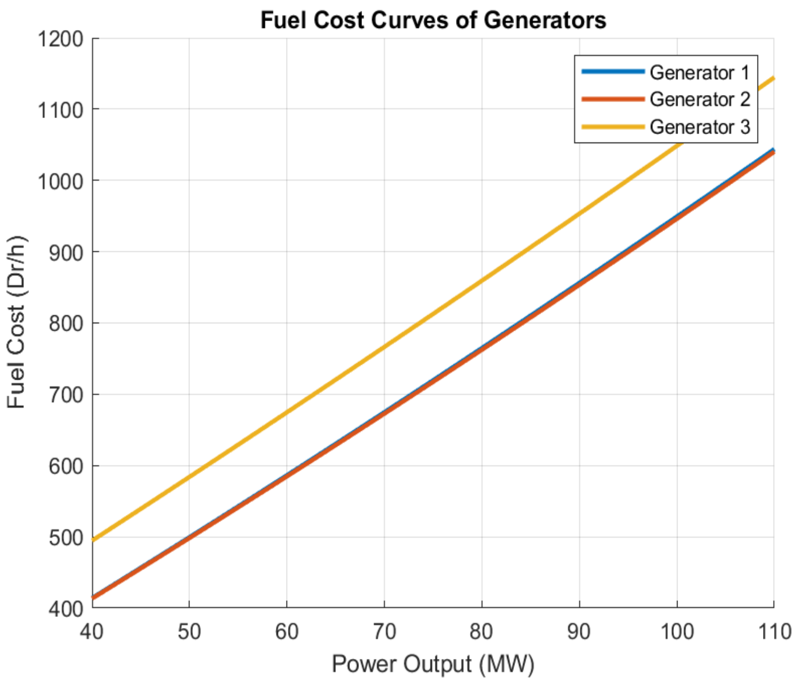

Figure 3: Fuel Cost Curves of Generators

The ratio contribution of each generator to load demand is shown in Figure 4. Contributions are roughly Generator 1: 37%, Generator 2: 39%, Generator 3: 24%. This histogram dramatically illustrates that the bulk of the load comes from generator one and two, with a far lower contribution originating for generator number three. This kind of distribution indicates the ABC algorithm's economic preference for generators with smaller marginal costs.

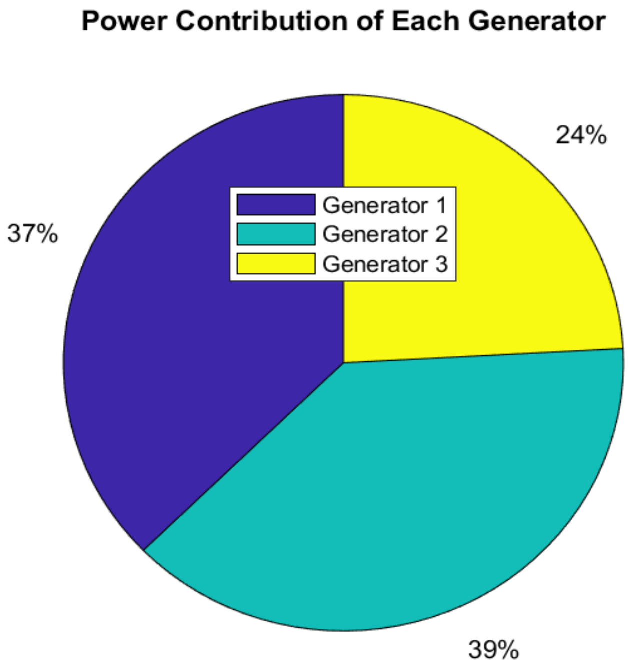

Figure 4: Power Contribution of Each Generator

Conclusion

The Artificial Bees Colony (ABC) method has been successfully applied in this study to solve the Economic Dispatch (ED) problem in power systems. The ED issue is nonlinear, nonconvex, and limited, which makes it difficult for conventional optimization methods to effectively find global optimal solutions. The ABC algorithm exhibits excellent exploration and exploitation skills, which makes it ideal for such challenging optimization tasks. It was inspired by the intelligent foraging activity of honey bees.

The suggested ABC-based strategy effectively reduces overall generation costs while meeting all operational requirements, such as power balancing and generator output limitations, according to simulation findings on common test systems. The ABC algorithm has better convergence characteristics, higher solution accuracy, and robustness against local optima when compared to traditional and specific heuristic optimization techniques. Furthermore, the ABC method is a viable substitute for real-world ED applications due to its ease of implementation and adaptability in managing different cost functions and limitations.

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