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Optimizing Multi-objective Combined Economic Dispatch Problem using MOBMO

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ABSTRACT

This project presents the development and application of the Multi-Objective Barnacles Mating Optimization (MOBMO) algorithm in resolving Multi-Objective Economic Dispatch (MOED) problems in power generation systems. The MOBMO algorithm, inspired by barnacles' mating behavior, integrates adaptive exploration and exploitation strategies to minimize both the generation cost and environmental emissions in complex non-convex dispatch scenarios, particularly those with the Valve Point Effect (VPE) effect. The strategy employs a weighted sum technique for dual objective mapping into a single fitness function to facilitate efficient multi-objective optimization. Simulation was executed on the IEEE 30-Bus Reliability Test System using various active power loading levels (load multipliers 1.1 and 1.2). The outcomes indicated that MOBMO outperformed unoptimized scenarios by producing significantly lower total fitness values. For instance, for a 1.1 load multiplier using weight factors $w1$ = 0.1, $w2$ = 0.9, MOBMO achieved an overall fitness of 569.9467 compared to the pre-optimized value of 4.1049e+03. The above outcomes confirm the capability of MOBMO to provide adaptive and robust optimization under dynamic conditions with a valid solution for cost-effective and eco-friendly power dispatch.

1. Introduction

The operation of modern power systems involves complex decision-making processes that must balance economic efficiency with environmental responsibility. One of the primary challenges in this context is the Multi-Objective Economic Dispatch (MOED) problem, where power generation must be scheduled in a way that minimizes operational costs while reducing pollutant emissions. As global electricity consumption increases, the urgency of developing optimization techniques that handle both economic and ecological objectives grows proportionally. However, solving these multi-objective problems becomes increasingly difficult due to the presence of nonlinear constraints and the complex characteristics of real-world power systems [2,7].

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Traditional optimization methods, such as Linear Programming (LP), Quadratic Programming (QP), and Dynamic Programming (DP), have been widely used in the past to address economic dispatch problems. While effective in structured and convex scenarios, these techniques often falter when applied to the non-convex nature of practical ED problems. These methods struggle to model nonlinear cost curves and fail to adequately respond to challenges like the Valve Point Effect (VPE), which introduces ripples into cost functions due to the physical constraints of generators [17]. In such cases, conventional techniques can result in suboptimal or infeasible solutions, limiting their practicality in real-time power dispatch environments [1].

As a result, research has shifted towards metaheuristic and nature-inspired algorithms, which offer greater flexibility and adaptability. These techniques do not require gradient information and are capable of navigating complex and discontinuous solution spaces. Among the many approaches, bio-inspired algorithms have proven to be particularly effective in power system optimization due to their dynamic search behaviors and robustness against local optima [3]. The integration of Multi-Objective Optimization (MOO) into these techniques enables simultaneous consideration of competing objectives, leading to more balanced and practical solutions [4,12].

One such promising method is the Barnacles Mating Optimization (BMO) algorithm, which mimics the unique reproductive behavior of barnacles to generate diverse and high-quality solutions. BMO leverages both exploration and exploitation phases to improve convergence and ensure global search capabilities [13]. However, while BMO is effective in single-objective scenarios, real-world applications such as economic dispatch demand a multi-objective framework to handle the trade-offs between cost and emission objectives. To fill this gap, this study proposes the Multi-Objective Barnacles Mating Optimization (MOBMO) algorithm, which adapts BMO into a multi-objective context using the Weighted Sum Method (WSM) to combine objectives into a single fitness function [5,6].

The MOBMO algorithm applies adaptive reproduction and mutation operators to ensure solution diversity and robustness, especially under dynamic load conditions and nonlinear generator behaviors. The optimization process begins with the generation of a random population of candidate solutions (barnacles), followed by iterative mating and fitness evaluation steps. The resulting offspring are evaluated based on a fitness function that incorporates both cost and emission components. This biologically inspired structure enables MOBMO to explore the solution space effectively and produce Pareto-optimal results that are well-suited for practical implementation in modern grid systems [6].

To evaluate the performance of MOBMO, the algorithm is tested on the IEEE 30-Bus Test System across multiple loading scenarios, including active and reactive power demands. Simulation results demonstrate that MOBMO outperforms the non-optimized methods by consistently producing lower total fitness values under varying weight configurations.

2. Methodology

For the ease of comprehension of the structure and working of the proposed Multi-Objective Barnacles Mating Optimization (MOBMO) algorithm, a detailed flowchart has been represented in Figure 1. The flowchart is utilized to represent sequential step-by-step operations of the optimization process from the initial population generation stage to the final convergence stage. It includes simple building blocks like fitness calculation, mating strategy, offspring creation, and population updating. With reference to this flowchart, readers can better comprehend the logical sequence and integration of the multi-objective optimization techniques used in this study, specifically in solving the non- convex economic dispatch issues with multiple constraints.

2.1 Problem Formulation

To find the optimal power generation which resulted in the minimum cost and fulfil all the constraints, BMO is applied. The optimization process is started by setting the number of barnacles representing the candidate of solution. All the information regarding the cost coefficients, boundaries and constraints are gathered to calculate the cost of power generation. Where equation [1] consists of the constants a_i, b_i and c_i represent the cost coefficients of the i_{th} generator. The cost minimization objective is expressed in form of quadratic function as a formula given.

$$C_i(P_i) = \sum_{i=1}^{N} a_i + b_i P_{Gi} + c_i P_{Gi}^2 \quad (1)$$

where, ai (\$/h), bi (\$/Hmw) and ci (\$/hMW2) are the fuel coefficient for thermal units in Eq. (1). The emission can be represented by a combination of exponential and polynomial terms for the power units. The emission minimization objective is modeled as Eq. (2).

$$F_{emission} = \sum_{i=1}^{n} [10^{-2}(\alpha_i P_i^2 + \beta_i P_i + \gamma_i) + \varphi_i exp(\lambda_i P_i)] \quad (2)$$

where ai, βi, γi, ϕi and λi are emission coefficient characteristic of the generator. To address the intertwined economic and emission dispatch issue, the two objective functions can be transformed into a unified

$$F_{Total} = w_1 F_{cost} + w_2 F_{emission} \quad (3)$$

where F_{cost} represents the fitness function for the overall generation cost, $F_{emission}$ represent the fitness function for the overall emission then $w_1 + w_2 \epsilon$ represents the weight coefficient.

2.2 Implementation of MOBMO

The MOBMO algorithm is one of the most recent bio-inspired optimization techniques developed for solving the multi-objective economic dispatch problems. Economic dispatch is a process of allocating optimal power generation resources to meet the demand with minimum cost and environmental impacts. MOBMO takes inspiration from barnacles mating strategies to effectively explore and exploit the search space. It enables the algorithm to consider the nonlinear and non-convex multi-objective economic dispatch (MOED) problems with a good balance in the trade- off between the conflicting objectives.

MOBMO employs adaptive operators to enhance diversity in solutions for better efficiency of global search, while fine-tuning the solutions by focused local search mechanisms. It is designed to solve a wide range of economic dispatch problems, including active and reactive power loading cases. Comparative studies are performed to assess the performance of the algorithm. These studies reveal that the algorithm is very effective in providing high-quality solutions with faster convergence and higher computational efficiency for solving real-world economic dispatch challenges.

Barnacle mating optimization solves multi- objective optimization problems by incorporating weighted sum approach into barnacle mating optimization. Multi- objective optimization involves optimization under conflict objectives and usually seeks to find a set of solutions characterized as optimal trade-offs among several objectives. In MOBMO, the search process is driven by the mating behavior of barnacles. The proposed approach molds the exploration and exploitation phases in BMO into a multi- objective framework that makes it possible for algorithms to strike an appropriate balance between competing objectives, which is minimizing generation costs and pollution emissions in an economic dispatch problem.

In solving the optimization problem while maintaining diversity, MOBMO evolves mutation operators for appropriate adaptive management. Weighted-sum strategies are usually one of several procedures that tackle the presence of numerous objectives: aggregative objects like cost and emission using arbitrary variable weights depending on relative precedence. These weights allow the algorithm to adapt dynamically, giving emphasis either on minimizing cost or reducing emission according to the requirements of the problem. This approach, when coupled with MOBMO can balance conflicting objectives effectively, as befits the complex real-world challenge represented by the nonconvex economic dispatch problem; under such scenarios, it yields flexible and robust solutions meeting operational and environmental needs [5,6]. The optimization procedures of MOBMO is explained as follows:

Step 1: Initialization

The algorithm starts by randomly generating an initial population of barnacles (solutions). Each barnacle represents a potential solution to the optimization problem. The random numbers are typically generated using uniform distribution within the bounds of the decision variables. This is expressed as (4);

$$X = \begin{bmatrix} x_1^1 & x_1^2 & \dots & x_1^N \\ x_2^1 & x_2^2 & \dots & x_2^N \\ \vdots & \vdots & \vdots & \vdots \\ x_n^1 & x_n^2 & \dots & x_n^N \end{bmatrix} \tag{4}$$

where N is the number of generators whose power outputs are to be optimized, and n is the number of individuals. In ED optimization, x_1, x_2,,.. x_n, represent the power generated (P_g) at the generator buses.

Step 2: Fitness Calculation

The fitness value is determined by a weighted sum method considering two conflicting objectives of generation cost minimization and emission reduction. The mathematical expression for the fitness function is given by Eq. (3). Where $Fcost$ represent the total generation cost, modelled as a quadratic function of the power output from each generator while $Femission$ represents the total emission, modeled using a combination of quadratic and exponential terms to account for the nonlinear emission characteristics of the generators. Weight coefficients is declared as w_1 and w_2.

Step 3: Mating Phase

The members of the barnacle population are shuffled using randperm() operator in MATLAB to choose a parent barnacle who will be paired for mating in order to produce offspring. The male and female barnacles are specifically identified as barnacle_m and barnacle_d, respectively. The MATLAB syntax can be written as in barnacle_m = randperm (n) (5)

barnacle_d = randperm (n) (6)

Step 4: Offspring Generation

The new off-springs generation is based on the principle of Hardy-Weinberg equilibrium. The new off-spring, $X_N\_newchild$ generated from the following expressions:

$$X^N{}_i\_new = px^N\, barnacle\_d + qx^N\, barnacle\_m \quad (7)$$

Where *p* is the normally distributed random numbers, *q = (1- p),* X^N *barnacle_d* and X^N *barnacle_m* are the variables of Dad and Mum of barnacles respectively which has been selected for mating.

Step 5: Combination

The newly generated offspring population is combined with the existing parent population. This step increases the number of candidate solutions, providing a larger pool for the selection process. The combination step ensures the algorithm retains only high-quality solutions from previous iterations [6].

$$\text{Population} = \begin{bmatrix} \text{Accepted parent} \\ \text{Offspring individuals} \end{bmatrix} \quad (8)$$

Step 6: Define New Generation

The combined population is evaluated, and the best solutions are selected to form the next generation. Selection is based on the fitness values; hence, solutions with better trade-offs between cost and emission objectives will remain in the solution set.

Step 7: Convergence Test

Next is the calculation of maximum and minimum fitness values of the population, on grounds of which convergence is checked. The difference between those calculated values of maximum and minimum determines convergence: if it is below a threshold level, then the algorithm converges. This ensures that the algorithm terminates only when an optimal or near-optimal solution is identified. If the convergence criteria are satisfied, the optimization process is stopped and the best solution returned. Otherwise, the algorithm loops back to refine the solutions, iterating from the earlier steps until convergence is achieved.

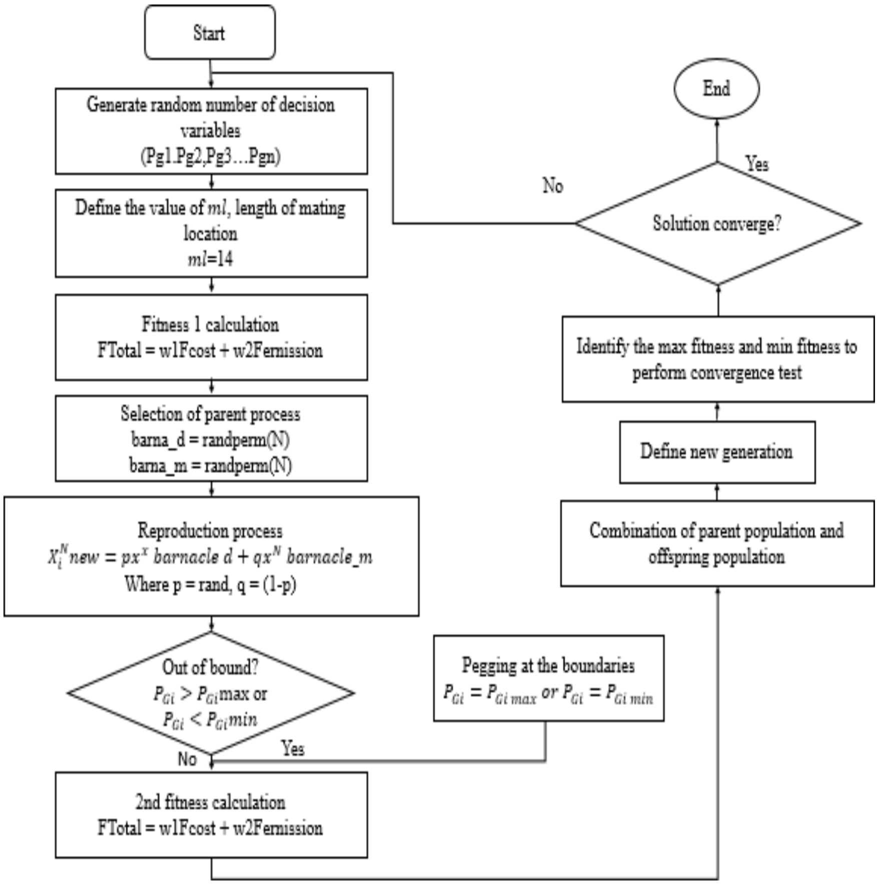

Fig. 1. Flowchart of developed MOBMO

3. Results

This section presents the results of the developed MOBMO when conducted using the IEEE 30-Bus RTS under generator standard condition. The efficiency of MOBMO is tested under active power loading scenario non-convex Economic dispatch problem with valve point effect (VPE). The total fitness obtained was compared to pre-optimized values. To optimize both objectives simultaneously, weight sum method (WSM) was used. WSM adjusted the equation by varying the weighting factor w_1 = 0.1, w_2 = 0.9, w_1 = 0.5, w_2 = 0.5 and w_1 = 0.9, w_2 = 0.1, where with each value of weightage producing corresponding values for the total generation cost and total emission. The main goal of this study is to solve the non-convex ED problem, which yields the comparison value between the overall fitness values with and without optimization.

Table 1
Power generated and total fitness optimal solutions solved by MOBMO under active power loading scenario (1.1 load multiplier)

Pre-optimized	4.1049e+03		
Load Multiplier	1.1		
Weight / Pg	w_1=0.1, w_2=0.9	w_1= 0.5, w_2=0.5	w_1=0.8, w_2=0.2
$Pg1$	136.0721	183.3324	179.1062
$Pg2$	33.4801	48.3411	57.6143
$Pg5$	49.3978	38.0946	26.0423
$Pg8$	33.5348	15.7172	22.0055
$Pg11$	23.1394	20.9027	22.9622
$Pg13$	37.4534	14.9342	14.3307
Total Fitness	569.9467	2.2534e+03	3.5048e+03

Table 1 shows the findings for the non-convex MOBMO with and without optimization under the generator outage scenario for six generators. MOBMO was used to meet the conflicting aims, with specific weight factor of w_1 = 0.1, w_2 = 0.9, w_1= 0.5, w_2= 0.5 and w_1= 0.8, w_2= 0.2.

From the tabulated results, MOBMO managed to solve the objectives with the lowest total fitness for each weighted coefficient sets but when w_1= 0.1, w_2= 0.9 the total fitness is 569.9467 which is the lowest. Whereas, when the weightage is w_1= 0.5, w_2= 0.5 the total fitness is 2.2534e+03 and for the last weightage w_1= 0.8, w_2= 0.2 the total fitness is 3.5048e+03.

As a result, when compared with or without optimization, the recommended approach succeeds in finding the least optimum solution. The lowest optimal solutions solved by MOBMO, with optimal sizing are $Pg1$= 136.0721 MW, $Pg2$ = 33.4801 MW, $Pg5$= 49.3978 MW, $Pg8$ = 33.5348 MW, $Pg11$ = 23.1394 MW and $Pg13$ = 37.4534 MW.

Table 2
Power generated and total fitness optimal solutions solved by MOBMO under active power loading scenario (1.2 load multiplier)

Pre-optimized	4.1049e+03		
Load Multiplier	1.2		
Weight Coefficient / Pg	w_1=0.1, w_2=0.9	w_1= 0.5, w_2=0.5	w_1=0.8, w_2=0.2
$Pg1$	179.1082	179.1056	222.1408
$Pg2$	61.9451	70.9117	30.7240
$Pg5$	44.8480	45.7568	45.9009
$Pg8$	32.0463	19.8136	21.0165
$Pg11$	16.8111	21.6769	18.4350
$Pg13$	15.7584	13.6595	14.6575
Total Fitness	663.8416	2.4222e+03	3.7427e+03

The findings of power generated and total fitness under active power loading when the load is increased by 1.2 multiplier are shown in Table 2. Using MOBMO and the same weight coefficients, the competing goals were resolved. From the tabulated results, MOBMO managed to solve the objectives with the lowest total fitness for each weighted coefficient sets. When w_1= 0.1, w_2= 0.9 the total fitness is 663.8416 which is produced by MOBMO. Whereas, when the weightage is w_1= 0.5, w_2=0.5 the fitness is 2.4222e+03 and for the last weightage w_1=0.8, w_2= 0.2 the total fitness is

3.7427e+03. Hence, the suggested algorithm is achieved in obtaining the lowest optimal solution for active power loading scenario with or without optimization. The optimal power generation sizes determined by MOBMO to achieve the lowest optimal solutions are $Pg1$= 179.1082 MW, $Pg2$ = 61.9451 MW, $Pg5$= 44.8480 MW, $Pg8$ = 32.0463 MW $Pg11$ = 16.8111 MW and $Pg13$ = 15.7584 MW

4. Conclusions

This study evaluated the effectiveness of the proposed Multi-Objective Barnacles Mating Optimization (MOBMO) algorithm in addressing non-convex Economic Dispatch (ED) problems under varying loading conditions of active power loading. The IEEE 30-Bus test system was employed to simulate the developed algorithm with 1.1 and 1.2 load multipliers. MOBMO was executed with three distinct sets of weight coefficients ($w_1 = 0.1, w_2 = 0.9$), ($w_1 = 0.5, w_2 = 0.5$), and ($w_1 = 0.8, w_2 = 0.2$); to reflect different optimization priorities between cost minimization and emission reduction. The optimization results demonstrated that MOBMO consistently outperformed the pre-optimized value by achieving lower total fitness values across all loading conditions. Configurations prioritizing emission minimization produced the lowest fitness values, underscoring the algorithm's capability to reduce environmental impact. Similarly, cost-focused settings also yielded improvements over the baseline, highlighting the algorithm's adaptability in managing trade-offs between conflicting objectives. Furthermore, the power generated distributions varied across different weight settings, illustrating MOBMO's dynamic adaptability to system requirements. Overall, the results confirm that MOBMO is a robust and efficient optimization tool for solving complex, constrained, multi-objective economic dispatch problems, offering significant advantages in both economic and environmental performance.

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