# A novel multi-objective economic load dispatch solution using bee colony optimization method

**Wanchai Khamsen[1], Chiraphon Takeang[1], Thawinan Janthawang[1], Apinan Aurasopon[2]**
[1]Department of Electrical Engineering, Faculty of Engineering, Rajamangala University of Technology Lanna, Lampang, Thailand
[2]Department of Electrical Engineering, Faculty of Engineering, Mahasarakham University, Maha Sarakham, Thailand

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**ABSTRACT**

This article presents a novel multi-objective economic load dispatch solution with the bee colony optimization method. The purposes of this research are to find the lowest total power generation cost and the lowest total power loss at the transmission line. A swarm optimization method was used to consider the non-smooth fuel cost function characteristics of the generator. The constraints of economic load dispatch include the cost function, the limitations of generator operation, power losses, and load demand. The suggested approach evaluates an IEEE 5, 26, and 118 bus system with 3, 6, and 15 generating units at 300, 1,263, and 2,630 megawatt (MW) and uses a simulation running on the MATLAB software to confirm its effectiveness. The outcomes of the simulation are compared with those of the exchange market algorithm, the cuckoo search algorithm, the bat algorithm, the hybrid bee colony optimization, the multi-bee colony optimization, the decentralized approach, the differential evolution, the social spider optimization, and the grey wolf optimization. It demonstrates that the suggested approach may provide a better-quality result faster than the traditional approach.



***Corresponding Author:***

Chiraphon Takeang
Department of Electrical Engineering, Faculty of Engineering, Rajamangala University of Technology Lanna
Lanna Lampang, 200 Moo 17 Pichai Subdistrict, Muang District, Lampang 52000, Thailand
Email: chiraphon@rmutl.ac.th

## 1. INTRODUCTION

At present, the electrical system is constantly evolving. This makes the stability of the power system essential to power generation planning, as the demand for electricity is likely to increase. As a result, electricity consumption is constantly changing. Therefore, it is important to produce enough electricity to fulfill the demand, and it is important to consider the cost of producing power. That is, the goal of economic load dispatching is to identify each generator's optimum capacity. The total cost of production is minimal and complies with the system's various mandatory conditions, so finding the optimal value can be considered a problem.

The economic load dispatch (ELD) solution used can be summarized in two forms. The first numerical method is solvable using mathematical operations like lambda iteration [1], gradient method [2]–[4], LaGrangian relaxation [5], dynamic programming [6], and linear programming [7]. These methods mentioned above are methods of finding the right solution to the sub-area (local optimal), so the answer is not the most appropriate answer. The second method, the metaheuristics method, can solve nonlinear problems of reliable and fast production cost functions such as particle swarm optimization (PSO) [8]–[15], ant colony optimization (ACO) [16], [17], ant lion optimization (ALO) [18], simulated annealing (SA) [19], [20], tabu search algorithm (TS) [21], [22], cuckoo search algorithm (CSA) [23], [24], firefly algorithm (FA) [25], [26], teaching learning algorithm (TLA) [27], backtracking search algorithm (BSA)

[28], genetic algorithm (GA) [29], bat algorithm (BA) [18], [30], rooted tree algorithm (RTO) [31], decentralized approach (DE) [32], hybrid particle swarm optimization-ant colony optimization (PSO-ACO) algorithm [33], differential evolution with biogeography-based optimization (DE/BBO) [34], modified grey wolf optimization (MGWO) [35], social spider algorithm (SSA) [36], exchange market algorithm (EMA) [37], and bee colony optimization (BCO) [38]–[43]. The above methods are rational ways of finding answers. Able to find the right answer in all areas (global optimum) with fast processing speed and solve complex problems. However, in some cases, endemic answers may be obtained, and convergence to answers is relatively slow since it is an algorithm that starts with randomization. Among the algorithms mentioned, BCO is an effective method to solve ELD problems. It takes fewer parameters, and the quality of the answers is good. Demonstrating superior performance over other algorithms makes BCO suitable to be used to find answers. Based on past research, numerous methodologies have been suggested to address ELD issues, primarily concentrating on minimizing total production expenses. Another reason for the high cost is transmission line loss, which directly affects the cost. Therefore, this research focuses on ELD for considering the lowest total costs and lowest total power losses of transmission lines and using the BCO method to solve the problem.

This article presents a multi-objective economic load dispatch solution, taking into account the fuel costs of smooth and non-smooth functions. The system's conditions and limitations include the generator limit, the power loss from the transmission line, and the rated load. We tested the system using 3 units, 6 units, and 15 units of generators, each with power requirements of 300, 1,263, and 2,630 MW, respectively. The test results from the suggested approach are compared with those from the bee colony optimization, hybrid bee colony optimization (HBCO), modified hybrid logistic bee colony optimization (MHLBCO), particle swarm optimization-ant colony optimization, hybrid particle swarm optimization (HPSO), particle swarm optimization, modified particle swarm optimization (MPSO), tuning variance adaptive chaotic-evolutionary particle swarm optimization (TVAC-EPSO), differential evolution with biogeography-based optimization, enhanced honey bee search algorithm (EHSA), cuckoo search algorithm, social spider algorithm, differential evolution, reverse Cauchy based algorithm (RCBA), modified grey wolf optimization, and exchange market algorithm methods.

## 2. PROBLEM FORMULATION

Economical load dispatch solutions aim to minimize the total cost of electricity generation while reducing transmission line losses to the lowest possible levels. These solutions operate under specific conditions and constraints in the electrical system. By addressing these factors, economical load dispatch ensures efficient resource utilization and enhances system reliability, as follows:

### 2.1. Objective function

Equations (1) and (2), which represent the main objectives of this research, are the lowest total production cost and the lowest transmission line loss.

$$Min\,(F) = \sum_{k=1}^{N} F_i(P_i) \tag{1}$$

$$Min(TL) = \sum_{k=1}^{N} P_{loss}(P_i) \tag{2}$$

where $F$ is the total cost of electricity generation, $TL$ is the total power loss at the transmission line, $i$ is the $i^{th}$ generator, $N$ is the total number of generators, $F_i(P_i)$ is the fuel cost of the $i^{th}$ generator and $P_{loss}(P_i)$ is the power loss at the transmission line.

$$OF = Min\left(\sum_{k=1}^{n} F_i(P_i) + \sum_{k=1}^{n} P_{loss}(P_i)\right) \tag{3}$$

The fuel cost function of each generator is not linear, as shown in Figure 1 and is calculated as (4):

$$F_i(P_i) = a_i P_i^2 + b_i P_i + c_i + \left| e_i \times \sin(f_i \times (P_{i,\min} - P_i)) \right| \tag{4}$$

where $a, b, c, e,$ and $f$ are the fuel cost coefficients of the $i^{th}$ generator and $P_{i,min}$ is the lower power capacity of the $i^{th}$ generator.

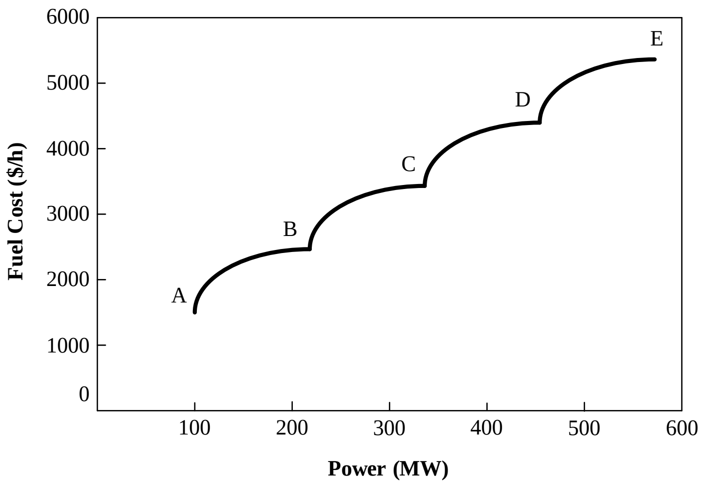


Figure 1. Non-smooth cost function of generator

### 2.2. Constraints

The power balancing constraint encompasses the electricity demand as indicated in (5) and the power loss inside the transmission system as delineated in (6).

$$\sum_{i=1}^{N}(P_i)=P_D+P_{loss} \quad (5)$$

$$P_{loss}=\sum_{i=1}^{N}\sum_{j=1}^{N}P_iB_{ij}P_j+\sum_{j=1}^{N}B_{oi}P_i+B_{oo} \quad (6)$$

where $P_D$ is the power load demand, $P_{loss}$ is the power loss at the transmission line, and $B_{ij}$, $B_{oi}$, and $B_{oo}$ are the loss coefficients of the transmission line. The generator rating limitation stipulates that the output capacity of each generator must adhere to the specified minimum and maximum production limits, as delineated in (7).

$$P_{i,\min}\le P_i\le P_{i,\max} \quad (7)$$

## 3. MULTI OBJECTIVE BEE COLONY OPTIMIZATION (MBCO)

The multi-objective economic dispatch process employs the bee colony method to identify solutions. The steps for implementing ELD with MBCO are listed as shown in Figure 2 and follows:

Step 1: Specify the BCO parameters as shown in Table 1 by testing them more than 100 times to get the best value.
Step 2: Using (6) to (8), generate the initial populations randomly ($N$) of the power capacity ($P_i$) that satisfies the constraints.
Step 3: Use (1) to (3) to evaluate the fitness values of the populations ($F$, $TL$, and $OF$) and sorting the fitness in ascending order.
Step 4: Select an answer from the estimated result of $M$ answers.
Step 5: Separate the good answer ($M$) into 2 sets: the best answer $E$ and the good answer $M – E$.
Step 6: Generating the solutions based on the chosen solutions within the neighborhood size ($n_{ep}$ around the best site ($E$), $n_{sp}$ around other sites ($M-E$)).
Step 7: Evaluating the answers obtained from $n_{ep}$ and $n_{sp}$ and checking the stopped criterion. Should the conditions be satisfied, cease operations. If not, return to step 2.

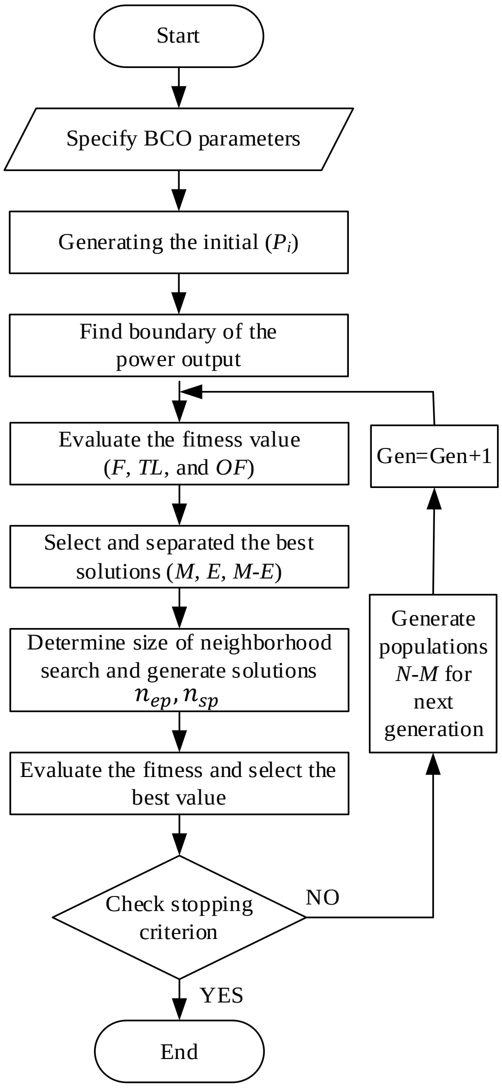


Figure 2. Flow chart of the proposed method

Table 1. Parameter of bee colony

| Parameters | Number |
|---|---|
| Initial population size of bees ($N$) | 150 |
| Amount of top-notch picks ($M$) | 80 |
| Total number of top destinations ($E$) | 30 |
| Amount of bees found in the areas with the best locations ($n_{ep}$) | 30 |
| Amount of bees found in and around various locations ($n_{sp}$) | 30 |

## 4. TEST CASE

This research employed MATLAB to validate the efficacy of the proposed technique. The testing system is categorized into three cases: i) three thermal generators with a need of 300 MW, ii) six thermal generators with a demand of 1,263 MW, and iii) fifteen thermal generators with a demand of 2,630 MW. As detailed below: the generator rating limitation stipulates that the output capacity of each generator must adhere to the specified minimum and maximum production limits, as delineated in (7).

### 4.1. Test case 1: 3 units of thermal generator

The system used in this study is an IEEE bus test system with a demand of 300 MW, comprising 5 buses and 3 thermal generators. The characteristics of each generator are detailed in Table 2. Additionally, the loss coefficients of the transmission lines are presented for further analysis, as follows:

$$B_{ij} = 10^{-3}\begin{bmatrix} 0.136 & 0.0175 & 0.184 \\ 0.0175 & 0.154 & 0.283 \\ 0.184 & 0.283 & 1.610 \end{bmatrix}$$

$$B_{oi} = [0.0046 \quad 0.0035 \quad 0.0019]$$

$$B_{oo} = [0.00055711]$$

Table 2. Parameter data of 3 units thermal generator

| Unit | $a_i$ | $b_i$ | $c_i$ | $e_i$ | $f_i$ | $P_{i,max}$ | $P_{i,min}$ | Prohibited zone |
|---|---|---|---|---|---|---|---|---|
| 1 | 0.00525 | 8.663 | 328.13 | 130 | 0.0636 | 250 | 50 | [105 117], [165 177] |
| 2 | 0.00609 | 10.04 | 136.91 | 90 | 0.0598 | 150 | 5 | [50 60], [92 102] |
| 3 | 0.00592 | 9.76 | 59.16 | 100 | 0.0685 | 100 | 15 | [25 32], [60 67] |

### 4.2. Test case 2: 6 units of thermal generator

The system analyzed in this study is an IEEE bus test system with a demand of 1,263 MW, consisting of 26 buses, 46 transmission lines, and 6 thermal generators. The characteristics of each generator are summarized in Table 3. Furthermore, the loss coefficients of the transmission lines are provided for detailed evaluation, as follows:

$$B_{ij} = 10^{-3} \times \begin{bmatrix} 0.017 & 0.012 & 0.007 & -0.001 & 0.005 & -0.002 \\ 0.012 & 0.014 & 0.009 & 0.001 & -0.006 & -0.001 \\ 0.007 & 0.009 & 0.031 & 0.0 & -0.010 & -0.006 \\ -0.001 & 0.001 & 0.0 & 0.024 & -0.006 & -0.008 \\ -0.005 & -0.006 & -0.010 & 0.006 & 0.129 & -0.002 \\ -0.002 & -0.001 & -0.006 & -0.008 & -0.002 & 0.015 \end{bmatrix}$$

$$B_{oi} = 10^{-2} \times [-0.3908 \quad -0.1297 \quad 0.7047 \quad 0.0591 \quad 0.2161 \quad -0.6635]$$

$$B_{oo} = [0.056]$$

Table 3. Parameter data of 6 units thermal generator

| Unit | $a_i$ | $b_i$ | $c_i$ | $e_i$ | $f_i$ | $P_{i,max}$ | $P_{i,min}$ |
|---|---|---|---|---|---|---|---|
| 1 | 0.0070 | 7.00 | 240 | 300 | 0.035 | 100 | 500 |
| 2 | 0.0095 | 10.00 | 200 | 200 | 0.042 | 50 | 200 |
| 3 | 0.0090 | 8.50 | 220 | 400 | 0.042 | 80 | 300 |
| 4 | 0.0090 | 11.0 | 200 | 159 | 0.063 | 50 | 150 |
| 5 | 0.0080 | 10.5 | 220 | 150 | 0.063 | 50 | 200 |
| 6 | 0.0075 | 12.0 | 190 | 150 | 0.063 | 50 | 120 |

### 4.3. Test case 3: 15 units of thermal generator

In this case, it is an IEEE 118 bus test system with a 2,630 MW demand that consists of 15 thermal generators. Table 4 displays each generator's characteristic values. Table 5 displays the ramp rate limit and prohibited operating zone characteristics of each generator.

Table 4. Parameter data of 15 units thermal generator

| Unit | $a_i$ | $b_i$ | $c_i$ | $e_i$ | $f_i$ | $P_{i,max}$ | $P_{i,min}$ |
|---|---|---|---|---|---|---|---|
| 1 | 0.000299 | 10.1 | 671 | 100 | 0.084 | 455 | 150 |
| 2 | 0.000183 | 10.2 | 574 | 100 | 0.084 | 455 | 150 |
| 3 | 0.001126 | 8.8 | 374 | 100 | 0.084 | 130 | 20 |
| 4 | 0.001126 | 8.8 | 374 | 150 | 0.063 | 130 | 20 |
| 5 | 0.000205 | 10.4 | 461 | 120 | 0.077 | 470 | 150 |
| 6 | 0.000301 | 10.1 | 630 | 100 | 0.084 | 460 | 135 |
| 7 | 0.000364 | 9.8 | 548 | 200 | 0.042 | 465 | 135 |
| 8 | 0.000338 | 11.2 | 227 | 200 | 0.042 | 300 | 60 |
| 9 | 0.000807 | 11.2 | 173 | 200 | 0.042 | 162 | 25 |
| 10 | 0.001203 | 10.7 | 175 | 200 | 0.042 | 160 | 25 |
| 11 | 0.003586 | 10.2 | 186 | 200 | 0.042 | 80 | 20 |
| 12 | 0.005513 | 9.9 | 230 | 200 | 0.042 | 80 | 20 |
| 13 | 0.000371 | 13.1 | 225 | 300 | 0.035 | 85 | 25 |
| 14 | 0.001929 | 12.1 | 309 | 300 | 0.035 | 55 | 15 |
| 15 | 0.004447 | 12.4 | 323 | 300 | 0.035 | 55 | 15 |

Table 5. Ramp rate limit and prohibited operating zone

| Unit | $P_i^o$ | $DR_i$ | $UR_i$ | Prohibited zone |
|---|---|---|---|---|
| 1 | 400 | 80 | 120 | |
| 2 | 300 | 80 | 120 | [185 225] [305 335] [420 450] |
| 3 | 105 | 130 | 130 | |
| 4 | 100 | 130 | 130 | |
| 5 | 90 | 80 | 120 | [180 200] [305 335] [390 420] |
| 6 | 400 | 80 | 120 | [230 225] [365 395] [430 455] |
| 7 | 350 | 80 | 120 | |
| 8 | 95 | 80 | 120 | |
| 9 | 105 | 65 | 120 | |
| 10 | 110 | 60 | 100 | |
| 11 | 60 | 60 | 100 | |
| 12 | 40 | 80 | 80 | [30 40] [55 65] |
| 13 | 30 | 80 | 80 | |
| 14 | 20 | 55 | 55 | |
| 15 | 20 | 55 | 55 | |

## 5. TEST RESULTS

The simulation results demonstrate high computational effectiveness and solution quality, confirming the viability of the suggested approach. To further validate its efficacy, three distinct test cases are analyzed in this study. These test cases provide comprehensive insights into the performance of the proposed method under various conditions.

### 5.1. Simulation results in case 1

In this instance, BCO and the projected MBCO were utilized to address the ELD issue. Table 6 and Figure 3 show the simulation results obtained from the proposed MBCO and BCO. The total cost and total loss of the proposed MBCO are less than those of the BCO method. The MBCO is conversed quickly after 44 iterations, while the BCO is conversed after 48 iterations. The results indicate that MBCO's solution quality can provide a better BCO method. Table 6 shows that the proposed MBCO has a lower of total cost and loss value than the other methods, such as PSO-ACO [33], DE/BBO [34], EHSA [19], and HPSO [10]. This is because the simulation results are better for the proposed method. The results demonstrate that MBCO's solution quality can outperform the other techniques.

Table 6. Results of case study 1

| Unit | MBCO | BCO | PSO-ACO | DE/BBO | EHSA | HPSO |
|---|---|---|---|---|---|---|
| 1 | 152.24 | 160.73 | 151.92 | 207.64 | 207.64 | 200.18 |
| 2 | 68.97 | 83.67 | 49.14 | 87.28 | 87.28 | 76.26 |
| 3 | 80.69 | 57.59 | 100 | 15.00 | 15.00 | 34.40 |
| Total P | 301.90 | 301.99 | 301.14 | 309.20 | 309.92 | 310.84 |
| TC ($/hr) | 3491.82 | 3510.51 | 3504.80 | 3619.76 | 3619.73 | 3623.11 |
| Ploss (MW) | 1.90 | 1.99 | 1.14 | 9.92 | 9.92 | 10.840 |

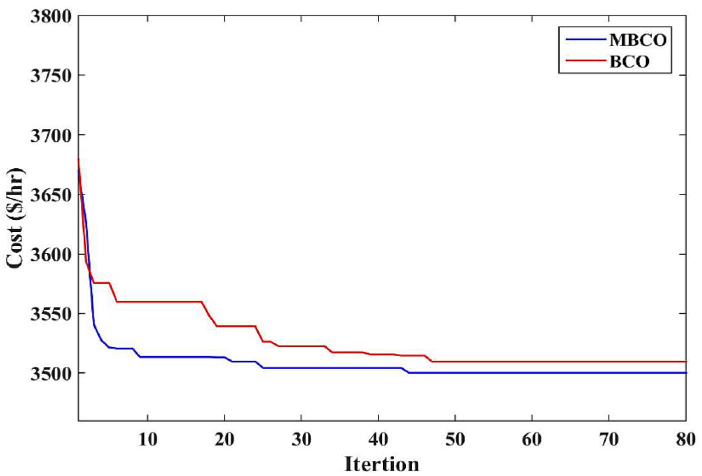


Figure 3. Convergence of the MBCO and BCO method in case 1

### 5.2. Simulation results in case 2

In this case, the ELD problem was resolved by the use of BCO and the proposed MBCO. Table 7 displays a comparison of the simulation results from the proposed MBCO, BCO, HBCO [40], MHLBCO [41], MPSO [11], CSA1 [23], DE [32], RCBA [30], and CSA2 [44] algorithms. The findings suggest that, when compared to other approaches, MBCO's solution quality can yield a superior outcome. The proposed method yields 15427.9 $/h and 5.98 MW of minimum cost and power loss, which are better than those of other methods. Figure 4 illustrates the convergence characteristics of the suggested MBCO in compared to BCO approaches. After 46 iterations, the MBCO converses quickly, while the BCO converses after 85 iterations. The results indicate that MBCO's solution quality can provide a better BCO method. It is evident that the suggested MBCO approaches converge to the ideal solution more quickly than the BCO techniques.

Table 7. Results of case study 2

| Unit | MBCO | BCO | HBCO | MHLBCO | MPSO | CSA1 | DE | RCBA | CSA2 |
|---|---|---|---|---|---|---|---|---|---|
| P1 | 463.95 | 455.01 | 470.31 | 451.34 | 447.19 | 447.48 | 448.27 | 444.70 | 446.9956 |
| P2 | 194.90 | 171.90 | 151.84 | 173.76 | 173.51 | 173.22 | 172.76 | 175.91 | 172.9307 |
| P3 | 234.59 | 259.21 | 268.44 | 257.61 | 260.96 | 263.38 | 263.44 | 256.33 | 261.9827 |
| P4 | 115.94 | 138.56 | 105.79 | 137.45 | 144.06 | 138.35 | 139.3 | 142.29 | 143.1165 |
| P5 | 154.77 | 166.37 | 177.01 | 163.72 | 163.22 | 165.41 | 165.28 | 169.92 | 163.4566 |
| P6 | 104.86 | 85.59 | 99.53 | 91.24 | 86.29 | 87.00 | 86.68 | 86.69 | 86.7619 |
| Total P | 1269.0 | 1276.64 | 1272.92 | 1275.12 | 1275.22 | 1275.45 | 1275.93 | 1275.84 | 1275.244 |
| TC ($/hr) | 15427.9 | 15440.5 | 15430 | 15439.5 | 15441 | 15443.1 | 15449.6 | 15449.6 | 15442.0 |
| Ploss (MW) | 5.98 | 12.24 | 9.74 | 12.12 | 12.22 | 12.45 | 12.95 | 12.93 | 12.200 |

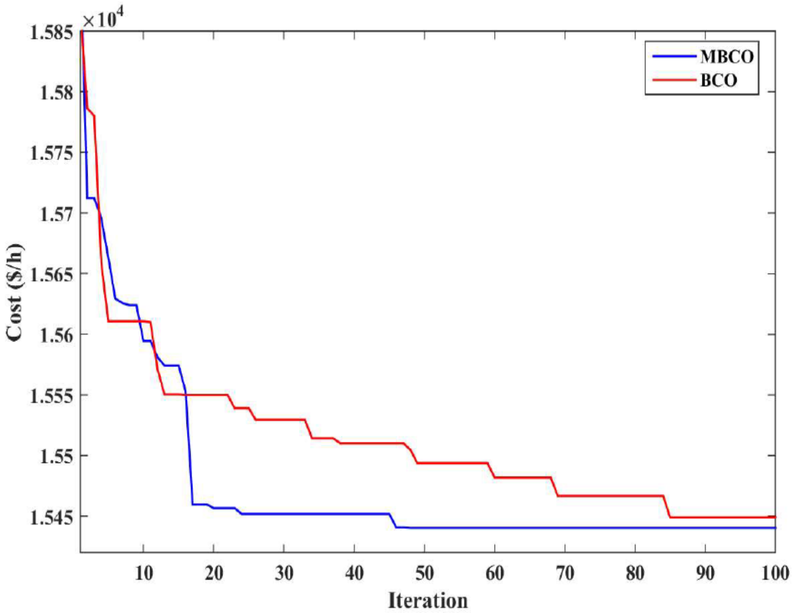


Figure 4. Convergence of the MBCO and BCO method in case 2

### 5.3. Simulation results in case 3

Table 8 displays the optimal dispatch solutions found using the proposed technique for the 2,630 MW load demand. Figure 5 shows the convergence profile for the MBCO approach. The MBCO converses rapidly after 59 iterations, whereas the BCO converses after 63 iterations. The findings suggest that MBCO's solution quality can offer an improved BCO technique. When compared to BCO methods, the suggested MBCO gets to the best answer faster than TVAC-EPSO [13], θ-PSO [15], MGWO [35], SSA [36], EMA [37], and enhanced self-converging swarm dynamic optimization (ESCSDO) [45]. Table 8 compares the outcomes from the suggested techniques with those from the literature. The MBCO method yields a minimum cost of 32587.5 $/h, surpassing the results of other methods. The findings demonstrate that the proposed algorithm surpasses alternative methods for optimal solutions.

Table 8. Results of case study 3

| Unit | MBCO | BCO | TVAC-EPSO | θ-PSO | MGWO | SSA | EMA | ESCSDO |
|---|---|---|---|---|---|---|---|---|
| P1 | 444.62 | 437.50 | 455.00 | 455.00 | 454.88 | 455.00 | 455.00 | 455 |
| P2 | 462.93 | 451.31 | 379.96 | 380.00 | 454.88 | 380.00 | 380.00 | 380.00 |
| P3 | 129.68 | 127.16 | 130.00 | 130.00 | 129.99 | 130.00 | 130.00 | 130.00 |
| P4 | 123.35 | 123.16 | 130.00 | 130.00 | 129.98 | 130.00 | 130.00 | 130 |
| P5 | 240.64 | 346.91 | 170.00 | 170.00 | 235.77 | 169.97 | 170.00 | 170 |
| P6 | 460.00 | 450.18 | 460.00 | 460.00 | 459.96 | 460.00 | 460.00 | 460 |
| P7 | 422.46 | 381.76 | 430.00 | 430.00 | 464.96 | 430.00 | 430.00 | 430 |
| P8 | 71.66 | 79.70 | 93.02 | 71.80 | 60.502 | 125.69 | 72.04 | 70.26 |
| P9 | 37.87 | 35.84 | 34.29 | 60.24 | 25.00 | 32.56 | 58.62 | 59.33 |
| P10 | 36.05 | 36.95 | 160.00 | 158.75 | 29.23 | 128.10 | 160.00 | 160.00 |
| P11 | 78.80 | 73.55 | 79.17 | 80.00 | 77.62 | 80.00 | 80.00 | 80 |
| P12 | 73.09 | 49.50 | 80.00 | 80.00 | 80.00 | 80.00 | 80.00 | 80 |
| P13 | 32.67 | 27.84 | 25.00 | 25.01 | 25.22 | 25.00 | 25.00 | 25.00 |
| P14 | 20.64 | 21.65 | 15.00 | 15.01 | 15 | 15.00 | 15.00 | 15.00 |
| P15 | 20.21 | 15.31 | 19.38 | 15.00 | 15.01 | 15.00 | 15.00 | 15.00 |
| Total P | 2654.68 | 2658.28 | 2660.83 | 2660.82 | 2657.99 | 2656.32 | 2660.66 | 2659.59 |
| TC ($/hr) | 32587.5 | 32606.9 | 32711.96 | 32706.6 | 32560.9 | 32662.5 | 32704.4 | 32692.4 |
| Ploss (MW) | 24.68 | 28.28 | 30.83 | 30.83 | 27.99 | 26.33 | 30.66 | 29.59 |

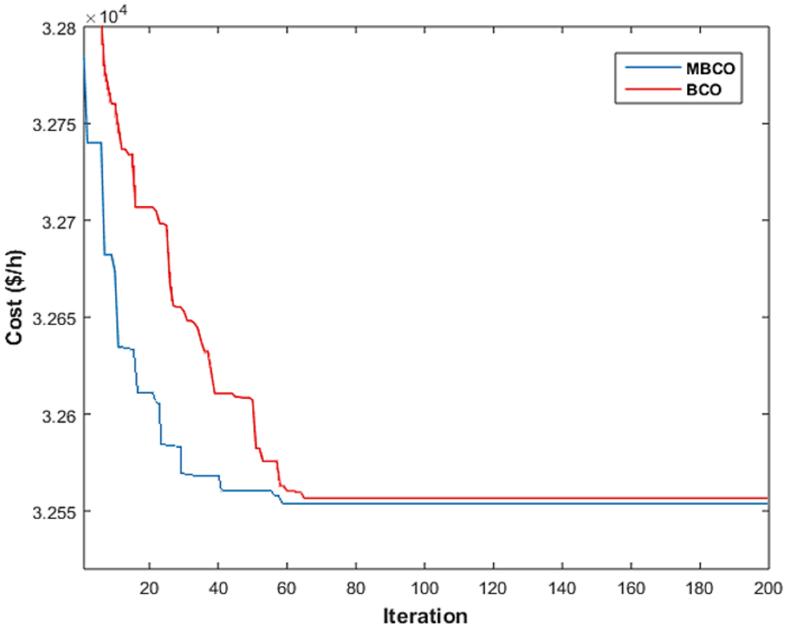


Figure 5. Convergence of the MBCO and BCO method in case 3

## 6. CONCLUSION

Economical load dispatch entails finding the lowest total cost within a variety of constraints. Past research has proposed several approaches to solve ELD problems, primarily focusing on minimizing total production costs. Another reason for the high cost is transmission line loss, which directly affects the cost. This research concentrates on ELD with the aim of minimizing both the overall costs and total power losses associated with transmission lines. This work presents a unique multi-objective approach to solve the ELD issue with non-smooth cost functions while taking into account real-world limitations, including ramp rate restrictions, valve point effects, forbidden operating zones, power losses, and load demand. The MBCO method is used to solve ELD problems with fast processing speed and solve complex problems. The performance of the proposed method is assessed using three case systems with 3, 6, and 15 units. The outcomes of the simulation are compared with those from the BCO, HBCO, MHLBCO, PSO-ACO, HPSO, q-PSO, MPSO, TVAC-EPSO, DE/BBO, EHSA, CSA, SSA, DE, RCBA, MGWO, EMA, and ESCSDO methods. The MBCO indicates that the method can produce high solution quality and computational efficiency, which also demonstrates its stability. Comparing the MBCO presented methodology with other approaches, the study findings verify that it can definitely yield a higher-quality solution, faster computing time, and better convergence characteristics. Future work can apply the proposed MBCO method to smooth the cost functions of each generator, thereby solving the economic problem. Due to its high performance, other meta-heuristics can adopt the proposed multi-objective method to solve the economic problem.

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## BIOGRAPHIES OF AUTHORS

**Wanchai Khamsen** is associate professor at Department of Electrical Engineering, Rajamangala University of Technology Lanna Lampang, Thailand. He was born in Lampang, Thailand in 1974. He graduated from Rajamamgla Institute of Technology with a Bachelor's degree in technical education in 1997, King Mongkut's Institute of Technology North Bangkok with a master's degree in electrical engineering in 2003 and Ph.D. in electrical and computer engineering of Mahasarakam University. Currently, he is associate professor at Faculty of Engineering, Rajamangala University of Technology Lanna Lampang. His research interests include ac choppers, converter systems for improving power quality, economic dispatch and optimization technique. He can be contacted at email: wanchai_kh@rmutl.ac.th.

**Chiraphon Takeang** is assistant professor at Department of Electrical Engineering, Rajamangala University of Technology Lanna Lampang, Thailand. He received a B.S. degree in technical education in electrical engineering from the King Mongkut's Institute of Technology North Bangkok, Thailand, in 2003, him M.Eng. degree in electrical engineering from the Rajamangala University of Technology Lanna, Chiang Mai, Thailand, in 2015 and he holds a Ph.D. in electrical and computer engineering, Mahasarakham University, where he has interests in electronics agriculture, smart farms, electric power systems, and economic load dispatch. He can be contacted at email: chiraphon@rmutl.ac.th.

**Thawinan Janthawang** is lecturer at Department of Electrical Engineering, Rajamangala University of Technology Lanna, Lampang Thailand. She graduated from Rajamangala University of Technology Lanna, Lampang, Thailand, she received his B.Eng. degree in 2021 and M.Eng. in electrical engineering on 2024. His research interests include economic dispatch, and optimization technique. She can be contacted at email: thawinan_ja65@rmutl.ac.th

**Apinan Aurasopon** is associate professor at Department of Electrical Engineering, Faculty of Engineering, Mahasarakham University, Thailand. He received his B.Eng. degree in electronic engineering from Northeastern College, Khon Kaen, Thailand, in 1995, his M.Eng. and Ph.D. degrees in electrical engineering from King Mongkut's University of Technology Thonburi, Bangkok, Thailand, in 2003 and 2007, respectively. His current research interests include soft-switched converters, ac choppers, converter systems for improving power quality, and the application of electronics and computer to agriculture. He can be contacted at email: apinan.a@msu.ac.th.