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# Multi-Objective Economic Dispatch Problems: An Evolutionary Programming Approach

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**ABSTRACT**

Optimizing multiple objectives is a common challenge in complex decision-making scenarios, where improving one objective often comes at the expense of another. In power system generation, two critical objectives must be simultaneously minimized: the total generation cost and the total emissions released. This study introduces a multi-objective optimization method developed to address these dual objectives. The proposed approach aims to identify the optimal solution to the economic dispatch problem, balancing the trade-off between minimizing generation costs and reducing environmental impact by lowering total emissions. Heuristic optimization is used to solve this multi-objective combined economic and emission dispatch (MOCEED) problems through the implementation of Multi-Objective Evolutionary Programming (MOEP). In this study, the Weighted Sum Method (WSM) is combined with the Evolutionary Programming (EP) technique to minimize both objectives. The developed approach is validated on the IEEE 30-Bus RTS, which consists of six generators. The effectiveness of the developed technique is evaluated and compared the results against scenarios without optimization. Simulations are performed using MATLAB software, and the results demonstrate that the proposed Multi-Objective Evolutionary Programming (MOEP) successfully identifies the optimal generator outputs, achieving significant reductions in both total generation cost and emissions. These results highlight the method's capability to provide superior solutions for multi-objective economic dispatch problems.

## 1. Introduction

One enduring difficulty in power system management and power generation in today's more sophisticated technology world is figuring out the most effective answer to the Economic Dispatch (ED) problem. An economic dispatch confirms electricity systems run efficiently, aiming to determine the optimal generator outputs to meet the total load demand in the most cost-effective way [1]. This

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objective has posed a significant challenge to power system networks for many years, prompting the development of numerous methods to address the issue [2,3]. Many problems encompass multiple objectives, making them more effectively approached as multi-objective problems. Traditional multi-objective optimization techniques, such as the aggregated sum, goal programming, and ε-constraint methods, typically involve transforming the optimization problem into a single-objective [4]. In essence, the goal is to minimize the generation cost associated with each generator's output. Beyond generation costs, optimizing transmission losses in the system is also crucial for ensuring the efficient operation of power systems. This indicates that only the entire generation cost was optimized to obtain the best value. This study aims to minimize both the generation cost and pollution emissions concurrently. This is because burning fuel at fossil fuel plants provides the required heat results in the dispersal of pollutants, which can contribute to global warming and environmental deterioration [5,6].

The heuristic optimization (HO) method effectively solved ED problems in modern power systems [7]. This method includes Genetic Algorithm (GA) [8,9], bottlenose dolphin [10], differential evolution [11], Particle Swarm Optimization (PSO) [12-15], salp swarm [16], whale optimization [17-19], gravitational search [20] and search group algorithm [21] surpass traditional techniques like linear and quadratic programming in finding global optima. HO methods excel in handling highly nonlinear ED problems with various cost curve shapes and do not require derivatives such as gradient vectors or Jacobian/Hessian matrices, making them suitable for non-convex and non-differentiable issues [22-24].

This study employs a heuristic optimization approach to address the conflicting multi-objectives in economic dispatch power system generation. Evolutionary Programming (EP) was selected among the various heuristic optimization methods. EP has demonstrated its effectiveness in solving multiple power system optimization issues. It is a probabilistic approach to global search that starts with a set of randomly generated candidate solutions, evolving through numerous generations or iterations toward improved solutions. The goal was to develop an algorithm capable of meeting all constraints and functions while delivering the most optimized solution for economic dispatch (ED) problem with multiple objectives. The introduced algorithm, Multi-Objective Evolutionary Programming (MOEP), attempts to address the joint challenges of multi-objective combined economic and emission dispatch (MOCEED) in the presence of Prohibited Operating Zones (POZ). EP was integrated with the weighted sum method to tackle the ED problem with multiple objectives. The weighted sum method is commonly used and has garnered significant attention in research due to its simplicity and ease of implementation compared to other approaches. This method involves assigning weights to different objectives and summing them to create a single scalar value, which can then be optimized [19][20].

Many researchers appreciate its straightforward nature, making it a popular choice in multi-objective optimization problems. While it may not capture all the complexities of the objective functions in certain cases, its ease of use makes it an appealing option for a wide range of applications, especially when dealing with problems where objectives are relatively well-defined. The primary aim of the proposed MOEP technique is to simultaneously minimize the total generation cost and emissions for both convex and non-convex ED problems. The effectiveness of the MOEP approach is validated using the IEEE 30-Bus system, considering scenarios involving generator outage contingency.

## 2. Methodology
### *2.1 Problem Formulation of Multi-Objective ED*

The combined economic and emission is a complex optimization problem involving multiple conflicting objectives. In this study, a weighting coefficient, $w$ is employed to transform the multi-objective function into a single-objective function. This allows the problem to be addressed using scalar optimization techniques. The transformation can be expressed mathematically as;

$$F_{Total} = wF_{cost} + (1-w)F_{emission} \quad (1)$$

where $F_{Total}$ is is the function to be optimized, $F_{cost}$ is the fitness function for the total generation cost, $F_{emission}$ is the fitness function for the total emission then $w_1+w_2 \in [0\ 1]$ is the weight coefficient.

The cost function is shown in Eq. (2), which is a quadratic function in terms of real power production and cost coefficients. The total cost for optimization is obtained by summing up the costs of all generators, as expressed in Eq. (3).

$$F_i\,(X_i) = |a_i + b_iP_i + c_iP_i^2| \quad (2)$$

$$minF_1 = C_s = \sum_{i=1}^{n} C_i(Pg_i) \quad (3)$$

The pollutant emissions from thermal power generating units are primarily influenced by their output power. These emissions mainly comprise atmospheric pollutants, such as sulphur oxides ($SO_2$) and nitrogen oxides ($NO_X$), produced by fossil-fuelled thermal generators. Mathematically, emissions are modelled using a combination of exponential and polynomial terms based on the power output of the units. Total pollution level can be represented as in Eqn. (4).

$$F_{emission} = \sum_{i=1}^{n}\left[10^{-2}\left(\alpha_iP_i^2 + \beta_iP_i + \gamma_i\right) + \varphi_i exp(\lambda_iP_i)\right] \quad (4)$$

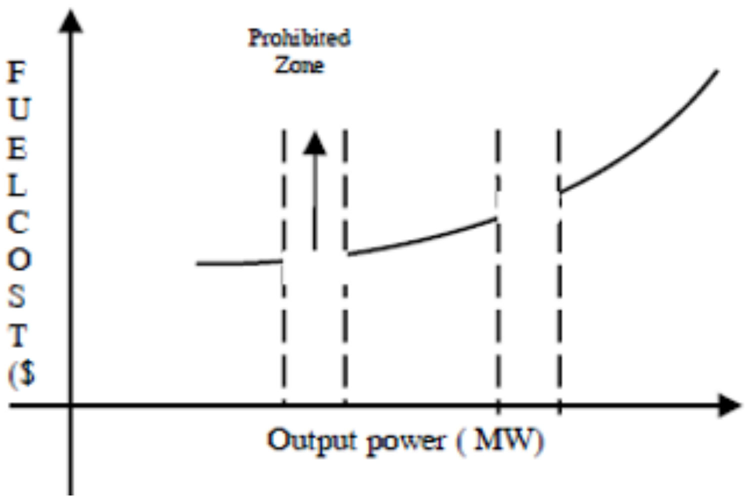


**Fig. 1**. The prohibited zone is due to steam valve point effects

The input-output characteristics of modern units are naturally nonlinear due to the impact of steam valve point effects and mechanical vibrations. A practical generator must consider the prohibited zone in power generation as shown in Figure 1 and it is typically avoided for better efficiency and stability. These constraints cause discontinuities in the cost curve and are defined as follows:

$$P_i^{min} \leq P_i \leq P_{i,1}^d$$

$$P_{i,j-1}^u \leq P_i \leq P_{j,1}^d \qquad j = 2,3 \ldots . n_i \tag{5}$$

$$P_{i,n_i}^u \leq \; P_i \leq P_i^{max}$$

where:

| | | |
|---|---|---|
| $j$ | = | Number of prohibited zones of unit $i$ |
| $P_i$ | = | Output power of generator $i$ |
| $P_i^{min}$ | = | Minimum power output limit of generator $i$ |
| $P_i^{max}$ | = | Maximum power output limit of generator *i* |
| $P_{i,j}^d$ & $P_{i,ni}^u$ | = | Lower and upper boundaries of prohibited operation zone *j* |

*2.2 Multi-Objective Evolutionary Programming (MOEP)*

Evolutionary Programming (EP) is a population-based optimization algorithm that evolves a randomly initialized population iteratively to identify optimal solutions. It employs an elitist selection mechanism and gradually refines potential solutions. In EP, solutions are represented as generation values. The fitness function evaluates the quality of solutions by minimizing or maximizing objective functions while ensuring constraints are satisfied and convergence criteria are met. The steps taken in EP optimization process are as follows.

A. Initialization

The initial population in the EP method consists of candidate dispatch combinations that satisfy all constraints. These candidates are randomly generated within the permissible range defined by the minimum and maximum generator limits, ensuring adherence to inequality constraints. This process applies to all generators at designated buses (bus 2, 5, 8, 11, and 13), while bus 1 serves as the slack bus. The value for bus 1 is computed using the Newton-Raphson method to ensure the equality constraint is met. The resulting values are termed parent individuals, forming the foundation for subsequent evolutionary steps in the algorithm.

B. Fitness 1 Calculation

As a Weighted Sum Method equation, fitness in this study refers to the objective functions, which include the cost and emission functions, as well as the use of Weighted Sum Method for MOEP. Fitness values are bound by the constraints imposed, setting minimum and maximum thresholds.

C. Mutation

The EP approach generates a new population for mutation by applying a Gaussian operator, which introduces normally distributed random variations with zero mean and a defined standard deviation to each component of the parent vectors. The offspring's objective function values are then calculated and compared. The best individuals from this evaluation will be selected to the next phase as offspring. This step produces a fitness output comprising 20 populations. Essentially, the mutation process enables parents from the previous phase to create offspring, with both parents and offspring competing to deliver the best results for subsequent iterations.

D. Fitness 2 Calculation

This process is a repetition of fitness calculation by implementing Eqn. (1) but using the new candidate from the mutation process. At this stage the total number of offspring produced are 20 individuals.

E. Combination and Selection

The selection process for solving the ED problem identifies non-dominated solutions within the combined population of parents and offspring, a total of 40 individuals using calculated fitness values for second time. Each solution is ranked based on how many other solutions outperform it, and the 40 solutions are sorted in ascending order of rank. The top 20 solutions are selected as parents for the next generation. These solutions, arranged by fitness values from minimum to maximum, form the basis for generating the next population, which undergoes further convergence tests.

F. Convergence Test

The iterative process evaluates the fitness values of newly generated populations, selecting the top 20 exemplary values for convergence analysis. Convergence is deemed achieved when the stopping criterion, set at 0.0001 in the MOEP algorithm, is met. If convergence is not attained, mutation and selection procedures are repeated until the maximum number of generations is reached. Convergence occurs only when both the objective function and fitness values align across all populations. The iteration process terminates upon achieving convergence, resulting in the final optimal solution for the economic dispatch problem.

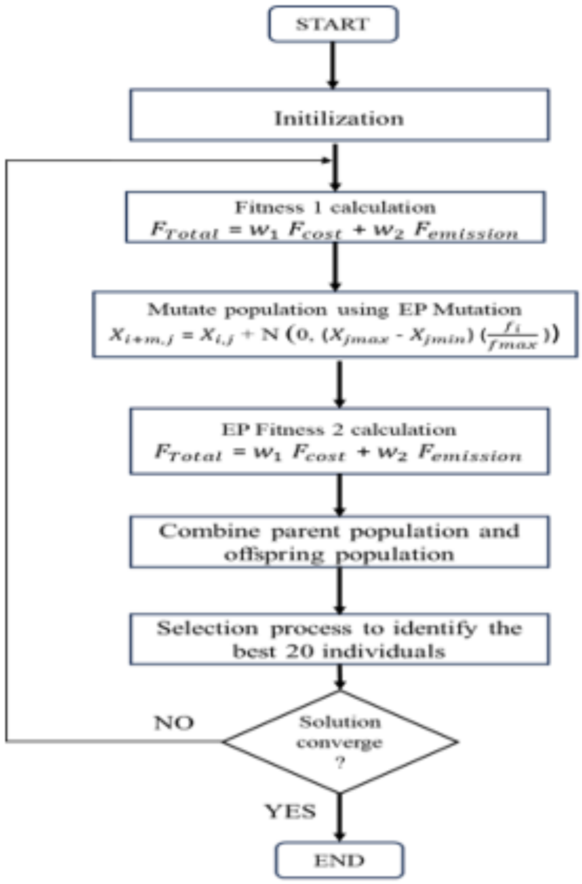


**Fig. 2**. The flowchart of the proposed multi-objective evolutionary programming optimization

## 3. Results

The developed MOEP has been verified to solve convex and non-convex ED problems to minimize the total generation cost and emission simultaneously. It is tested on IEEE 30-Bus RTS with six generators. Bus 1 was the slack bus while busses 2, 5, 8, 11, and 13 were generator buses. The remaining buses were assumed to be load buses. The set of weighting factors, Fa of ($w_1$=0.2, $w_2$=0.8), ($w_1$=0.5, $w_2$=0.5), and ($w_1$=0.8, $w_2$=0.2) are chosen in this study. Table 1 shows the power generator limits, cost, and emission coefficients for the IEEE 30-Bus System in solving these problems. There are two scenarios have been selected to assess the effectiveness of MOEP, which are convex and non-convex ED problems under generator outage, as tabulated in Table 2.

**Table 1**
Power generator limits, cost and emission coefficient for IEEE 30-Bus System

| No of Gen. | Cost Coefficients | | | Emission Coefficients | | | | | Generator Limit (MW) | | Prohibited Zone | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | A ($/h) | B ($/MWh) | C ($/MW$^2$H) | $\alpha$ | $\beta$ | $c$ | $n_i$ | $\delta_i$ | Min | Max | Min | Max |
| 1 | 240 | 7 | 0.007 | 80 | -0.805 | 0.018 | 0.655 | 0.02846 | 50 | 200 | 55 | 66 |
| 2 | 200 | 10 | 0.0095 | 50 | -0.555 | 0.015 | 0.5773 | 0.02446 | 20 | 120 | 21 | 24 |
| 5 | 220 | 8.5 | 0.009 | 60 | -1.355 | 0.0105 | 0.4968 | 0.0227 | 15 | 80 | 30 | 36 |
| 8 | 200 | 11 | 0.009 | 45 | -0.6 | 0.008 | 0.486 | 0.01948 | 10 | 55 | 25 | 30 |
| 11 | 220 | 10.5 | 0.008 | 30 | -0.555 | 0.012 | 0.5035 | 0.02075 | 10 | 50 | 25 | 28 |
| 13 | 190 | 12 | 0.0075 | 30 | -0.555 | 0.012 | 0.5035 | 0.02075 | 12 | 64 | 24 | 30 |

**Table 2**
Implemented Cases for Solving ED Problem

| Case | Scenario |
|---|---|
| Case 1 | Convex ED problem under generator outage - P8 and P11 |
| Case 2 | Non-convex ED problem under generator outage - P8 and P11 |

### *3.1 Scenario 1: Convex MOCEED Under Generator Outage P8 and P11*

The results for the convex MOCEED problem under the generator outage scenario, P8 is tabulated in Table 3. In this study, generator 8 was selected to be shut down randomly. The total fitness value improves from 1.5687x$10^3$ to 548.4678, when the weight coefficient of $w_1$=0.2, $w_2$=0.8 is applied, demonstrating a successful minimization of both objectives, the total generation cost and emissions simultaneously. This is a clear improvement over the non-optimized scenario. With the second set coefficient, $w_1$=0.5, $w_2$=0.5, the total fitness value is 1.3113x$10^3$ reflecting the trade-off between cost and emissions. While the emissions are lower than in the first optimization case, the cost is higher due to the balanced focus on both objectives. With a higher weight on cost minimization, $w_1$=0.8, $w_2$=0.2, the total fitness value is reduced to 2.0742x$10^3$ from the no-optimized scenario at 2.9265x$10^3$. This reflects a solution with the lowest emissions, albeit at a higher cost. This indicates a strong emphasis on reducing emissions at the expense of increased generation costs. The implementation of the MOEP algorithm in this convex multi-objective economic dispatch problem demonstrates its capability to simultaneously minimize total generation costs and emissions. The results highlight the importance of selecting appropriate weight coefficients based on the desired balance between cost and emissions. The optimization successfully achieves lower costs and emissions compared to the non-optimized scenario, with the ability to further design the solution based on specific objectives.

**Table 3**
Results for Convex MOCEED problem under generator outage scenario, P8 without optimization and with MOEP implementation

| | Without Optimization | | | With MOEP | | |
|---|---|---|---|---|---|---|
| Generator Outage | 8 | | | | | |
| Weight Coefficients | $w_1$=0.2, $w_2$=0.8 | $w_1$=0.5, $w_2$=0.5 | $w_1$=0.8, $w_2$=0.2 | $w_1$=0.2, $w_2$=0.8 | $w_1$=0.5, $w_2$=0.5 | $w_1$=0.8, $w_2$=0.2 |
| $P_1$ | 260.9985 | 260.9985 | 260.9985 | 137.5010 | 137.5010 | 137.5010 |
| $P_2$ | 40 | 40 | 40 | 25.2379 | 25.2379 | 25.2379 |
| $P_5$ | 0 | 0 | 0 | 62.7635 | 62.7635 | 62.7635 |
| $P_8$ | OFF | OFF | OFF | OFF | OFF | OFF |
| $P_{11}$ | 0 | 0 | 0 | 24.3322 | 24.3322 | 24.3322 |
| $P_{13}$ | 0 | 0 | 0 | 39.5159 | 39.5159 | 39.5159 |
| Generation cost ($/MWh) | 675.8062 | $1.6895x10^3$ | $2.7032x10^3$ | 516.5470 | $1.2914x10^3$ | $2.0662x10^3$ |
| Total Emission (lb/h) | 892.9018 | 558.0636 | 223.4126 | 31.9208 | 19.9505 | 7.9802 |
| Total Fitness | $1.5687x10^3$ | $2.2476x10^3$ | $2.9265x10^3$ | 548.4678 | $1.3113x10^3$ | $2.0742x10^3$ |

Table 4 presents the results of the convex MOCEED problem under a generator outage scenario, specifically when generator P11 is offline. The performance is evaluated both with and without the MOEP optimization. When the weight coefficient of $w_1$=0.2, $w_2$=0.8 is implemented, the total fitness value is improved to 691.3001 from $1.6095x10^3$, showing a better solution compared to the non-optimized case. While for weight coefficient, $w_1$=0.5, $w_2$=0.5, the total fitness solved by MOEP is $1.5749x10^3$ which is lower than without optimization, $2.3480x10^3$. The consistency continues when the weight coefficient is changed to $w_1$=0.8, $w_2$=0.2 with the total fitness minimized from $3.0866x10^3$ to $2.4584x10^3$. The optimization results steadily demonstrate better performance than the non-optimized case, with reduced generation costs and emissions in all scenarios. This indicates that the MOEP optimization method is effective in achieving an improved balance between conflicting objectives. By adjusting the weight coefficients, the optimization algorithm successfully minimizes both generation costs and emissions, achieving solutions that are more efficient than the non-optimized scenario. Depending on the weight coefficients, the optimization can prioritize cost reduction or emission minimization, providing flexibility in addressing the specific objectives of the power system.

**Table 4**
Results for Convex MOCEED with POZ under generator outage scenario, P11 without optimization and with MOEP implementation

| | Without Optimization | | | With MOEP | | |
|---|---|---|---|---|---|---|
| Generator Outage | 11 | | | | | |
| Weight Coefficients | $w_1$=0.2, $w_2$=0.8 | $w_1$=0.5, $w_2$=0.5 | $w_1$=0.8, $w_2$=0.2 | $w_1$=0.2, $w_2$=0.8 | $w_1$=0.5, $w_2$=0.5 | $w_1$=0.8, $w_2$=0.2 |
| P1 | 260.9985 | 260.9985 | 260.9985 | 174.0879 | 174.0879 | 174.0879 |
| P2 | 40 | 40 | 40 | 26.6016 | 26.6016 | 26.6016 |
| P5 | 0 | 0 | 0 | 38.6983 | 38.6983 | 38.6983 |
| P8 | 0 | 0 | 0 | 12.7129 | 12.7129 | 12.7129 |
| P11 | OFF | OFF | OFF | OFF | OFF | OFF |
| P13 | 0 | 0 | 0 | 40 | 40 | 40 |
| Generation cost ($/MWh) | 715.8062 | 1.7895x$10^3$ | 2.8632x$10^3$ | 609.4960 | 1.5237x$10^3$ | 2.4380x$10^3$ |
| Total Emission (lb/h) | 893.6506 | 558.0636 | 223.4126 | 81.8041 | 51.1276 | 20.4510 |
| Total Fitness | 1.6095x$10^3$ | 2.3480x$10^3$ | 3.0866x$10^3$ | 691.3001 | 1.5749x$10^3$ | 2.4584x$10^3$ |

### *3.1* Scenario 2: Non-Convex MOCEED Problem for generator outage P8 and P11

Table 5 tabulates the results for the non-convex MOCEED problem with POZ under the generator outage scenario, P8. Generator 8 was chosen at random to be shut down in this section. The total fitness value is 1.5687x$10^3$, indicating the performance of the system based on the non-optimized solution. The high total fitness value reflects the inefficiency in balancing cost and emissions. When the weight coefficient of $w_1$=0.2, $w_2$=0.8 is applied to MOEP, the optimal solution of total fitness is minimized to 611.0841. MOEP shows the same trend, when the total fitness obtained is reduced from 2.2476x$10^3$ to 1.3766x$10^3$ for weight coefficient $w_1$=0.5, $w_2$=0.5. The total fitness obtained for $w_1$=0.8, $w_2$=0.2 is 2.1421x$10^3$ when solved by MOEP and 2.9265x$10^3$ is a non-optimized solution. The results demonstrate the effectiveness of the MOEP algorithm in solving the non-convex economic dispatch problem under a generator outage scenario. The algorithm successfully balances the conflicting objectives of minimizing generation cost and emissions, providing solutions that outperform the non-optimized scenario. The flexibility to adjust the weight coefficients allows for designing the optimization based on specific priorities, whether cost reduction or emission minimization is the primary goal. The overall performance of the MOEP method is a clear improvement over the baseline, highlighting its potential for real-world applications in power system optimization.

**Table 5**
Results for Non-convex MOCEED with POZ under generator outage scenario, P8 without optimization and with MOEP implementation

| | Without Optimization | | | With MOEP | | |
|---|---|---|---|---|---|---|
| Generator Outage | 8 | | | | | |
| Weight Coefficients | $w_1$=0.2, $w_2$=0.8 | $w_1$=0.5, $w_2$=0.5 | $w_1$=0.8, $w_2$=0.2 | $w_1$=0.2, $w_2$=0.8 | $w_1$=0.5, $w_2$=0.5 | $w_1$=0.8, $w_2$=0.2 |
| P1 | 260.9985 | 260.9985 | 260.9985 | 173.8128 | 173.8128 | 173.8128 |
| P2 | 40 | 40 | 40 | 24 | 24 | 24 |
| P5 | 0 | 0 | 0 | 36 | 36 | 36 |
| P8 | OFF | OFF | OFF | OFF | OFF | OFF |
| P11 | 0 | 0 | 0 | 28 | 28 | 28 |
| P13 | 0 | 0 | 0 | 30 | 30 | 30 |
| Generation cost ($/MWh) | 675.8062 | $1.6895 \times 10^3$ | $2.7032 \times 10^3$ | 530.4914 | $1.3262 \times 10^3$ | $2.1220 \times 10^3$ |
| Total Emission (lb/h) | 892.9018 | 558.0636 | 223.4126 | 80.5927 | 50.3705 | 20.1482 |
| Total Fitness | $1.5687 \times 10^3$ | $2.2476 \times 10^3$ | $2.9265 \times 10^3$ | 611.0841 | $1.3766 \times 10^3$ | $2.1421 \times 10^3$ |

The results for a non-convex MOCEED problem with POZ consideration under generator outage scenario where generator P11 is offline randomly. The analysis compares the performance of the system with and without optimization using the MOEP method, with different weight coefficients for the conflicting objectives of minimizing generation cost and emissions. In the non-optimized scenario, the total fitness value is $1.6095 \times 10^3$, indicating a relatively inefficient trade-off between minimizing generation costs and emissions. The optimal solution of the total fitness obtained by MOEP has been decreased to 721.0568, by choosing the weight coefficient of $w_1$=0.2, $w_2$=0.8. MOEP also shows its dominance in reducing the total fitness from $2.3480 \times 10^3$ to $1.6367 \times 10^3$ for weight coefficient $w_1$=0.5, $w_2$=0.5. The optimization process consistently results in a lower total fitness value compared to the non-optimized scenario. The fitness values when the weight coefficient of $w_1$=0.8, $w_2$=0.2 is $2.5523 \times 10^3$ solved by MOEP and $3.0866 \times 10^3$ for non-optimized, reflecting the combined effect of both objectives, show improvements with the application of MOEP. The MOEP method consistently outperforms the non-optimized scenario, offering a more efficient solution with a better balance between generation cost and emissions.

**Table 6**
Results for Non-convex MOCEED with POZ under generator outage scenario, P11 without optimization and with MOEP implementation

| | Without Optimization | | | With MOEP | | |
|---|---|---|---|---|---|---|
| Generator Outage | 11 | | | | | |
| Weight Coefficients | $w_1$=0.2, $w_2$=0.8 | $w_1$=0.5, $w_2$=0.5 | $w_1$=0.8, $w_2$=0.2 | $w_1$=0.2, $w_2$=0.8 | $w_1$=0.5, $w_2$=0.5 | $w_1$=0.8, $w_2$=0.2 |
| $P_1$ | 260.9985 | 260.9985 | 260.9985 | 177.0182 | 177.0182 | 177.0182 |
| $P_2$ | 40 | 40 | 40 | 24 | 24 | 24 |
| $P_5$ | 0 | 0 | 0 | 36 | 36 | 36 |
| $P_8$ | 0 | 0 | 0 | 25 | 25 | 25 |
| $P_{11}$ | OFF | OFF | OFF | OFF | OFF | OFF |
| $P_{13}$ | 0 | 0 | 0 | 30 | 30 | 30 |
| Generation cost ($/MWh) | 715.8062 | $1.7895\times10^3$ | $2.8632\times10^3$ | 632.5418 | $1.5814\times10^3$ | $2.5302\times10^3$ |
| Total Emission (lb/h) | 893.6506 | 558.0636 | 223.4126 | 88.5150 | 55.3219 | 22.1287 |
| Total Fitness | $1.6095\times10^3$ | $2.3480\times10^3$ | $3.0866\times10^3$ | 721.0568 | $1.6367\times10^3$ | $2.5523\times10^3$ |

## 4. Conclusions

In summary, the Multi-Objective Evolutionary Programming technique proves highly effective in addressing both convex and non-convex ED challenges. Its core aim involves minimizing total generation costs and total emissions while ensuring optimal power system functionality under diverse constraints by obtaining the lowest total fitness value when compared to the solutions obtained without an optimization scenario. The integration of Evolutionary Programming with the Weighted Sum Method endows MOEP with the capability to effectively address the complexities and challenges inherent in optimizing power generation. This approach ensured a flexible and adaptive solution, capable of addressing the various needs of power system operations. In the future, the multi-objective ED problems can be enhanced by expanding the number of objectives. Other than that, this expansion may involve hybridizing more than one optimization technique to improve the optimal solutions obtained.


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