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Multi Objective Economic and Emission Dispatch of Multiple Generator IEEE Test System Using Improved Grey Wolf Optimization

Ashish Raj
Associate Professor
Department of Electrical & Electronics Engineering
Poornima University, Jaipur
Email: ashish.raj@poornima.edu.in

Abstract: The optimal operation of power generation systems is a critical endeavor in ensuring efficient resource utilization and mitigating environmental impacts. The Multi-Objective Economic and Emission Dispatch (MOEED) problem embodies the challenging task of simultaneously minimizing economic costs and environmental emissions while adhering to various technical constraints. In this study, we address the MOEED problem within the context of a multiple-generator IEEE test system, employing the Improved Grey Wolf Optimization (IGWO) algorithm. The paper summarizes a study on optimizing economic and emission dispatch in a multi-generator IEEE test system through an improved Grey Wolf Optimization (GWO) approach. The research focuses on the simultaneous achievement of economic efficiency and reduced emissions in power generation. By enhancing the conventional GWO algorithm, the study seeks to address the challenges of multi-objective optimization in a complex power system. The proposed method aims to strike a balance between economic cost and environmental impact by optimizing the generator outputs. Through comprehensive simulations and comparisons, the effectiveness of the improved GWO technique in achieving optimal trade-offs between economic and emission objectives is demonstrated, highlighting its potential applicability in real-world power systems.

Keywords: Multi-objective optimization, economic dispatch, emission dispatch, Grey Wolf Optimization, IEEE test system, improved algorithm, trade-offs, power generation, economic efficiency, environmental impact.

1. INTRODUCTION

In recent decades, the growing concerns regarding environmental degradation and the escalating demand for electricity have prompted the power generation industry to focus on optimizing power systems in a sustainable and efficient manner. The operation of power systems involves a complex interplay of various factors, such as economic costs, environmental emissions, and technical constraints. The economic dispatch (ED) problem aims to allocate the optimal generation output among different generators to meet the load demand while minimizing the total cost. Simultaneously, the emission dispatch (EMD) problem aims to determine the generator outputs that minimize the emissions produced during power generation. Balancing these two conflicting objectives is a challenging task, often referred to as the Multi-Objective Economic and Emission Dispatch (MOEED) problem.

In this context, optimization algorithms play a crucial role in finding optimal or near-optimal solutions for MOEED problems. Among these algorithms, metaheuristic techniques have gained prominence due to their ability to handle complex, non-linear, and multi-objective optimization problems. One such algorithm is the Grey Wolf Optimization (GWO) algorithm, inspired by the hunting behavior of grey wolves. The GWO algorithm has shown effectiveness in solving various optimization problems, including power system optimization. However, to enhance the performance of the GWO algorithm, researchers have proposed various modifications and improvements. One such enhancement is the Improved Grey Wolf Optimization (IGWO), which incorporates advanced mechanisms to increase convergence speed and solution quality. IGWO has demonstrated promising results in optimizing power systems, making it an attractive candidate for solving the MOEED problem.

The IEEE test systems, particularly the IEEE 30-bus and 57-bus test systems, have been widely adopted by researchers as benchmarks for evaluating the performance of optimization algorithms in power system applications. These systems capture the complexity and diversity of real-world power systems while providing a standardized platform for comparison.

The primary objective of this study is to apply the Improved Grey Wolf Optimization algorithm to solve the Multi-Objective Economic and Emission Dispatch problem in the context of the IEEE test systems. The study aims to achieve the following specific objectives:

- Develop a comprehensive understanding of the MOEED problem, its significance, and its challenges in power system optimization.
- Introduce the Grey Wolf Optimization algorithm and its enhanced version, the Improved Grey Wolf Optimization algorithm, highlighting their working principles and advantages.
- Analyze the IEEE 30-bus and 57-bus test systems as representative examples of real-world power systems, emphasizing their key features, generator characteristics, and load demands.
- Formulate the MOEED problem by considering economic costs, emission levels, and technical constraints, creating a robust optimization framework.
- Apply the IGWO algorithm to solve the MOEED problem for the IEEE test systems, optimizing both economic and emission objectives simultaneously.
- Perform a comprehensive tabular analysis of the obtained results, comparing the IGWO-based solutions with other optimization techniques in terms of convergence speed, solution quality, and computational efficiency.
- Assess the trade-off between economic and environmental objectives, highlighting the Pareto-optimal solutions that represent the optimal compromise between the conflicting objectives.

The modern world's insatiable appetite for electricity, coupled with the pressing need to mitigate environmental impacts, has posed a formidable challenge to power generation and distribution systems. The optimization of power systems has emerged as a paramount concern, demanding the simultaneous optimization of economic and environmental objectives. At the heart of this challenge lies the Multi-Objective Economic and Emission Dispatch (MOEED) problem—a complex puzzle requiring innovative solutions for balancing conflicting goals. The MOEED problem revolves around two primary objectives: economic cost minimization and environmental emission reduction. Economic dispatch aims to allocate generation outputs among multiple generators to meet the load demand while minimizing the operational costs, including fuel and maintenance expenses. On the other hand, emission dispatch seeks to limit the emissions produced during electricity generation, contributing to cleaner and more sustainable power systems. Traditionally, these objectives have been tackled individually, leading to suboptimal outcomes. However, the growing awareness of climate change and the need for efficient resource allocation have driven researchers and practitioners to seek integrated solutions that address both economic and environmental dimensions concurrently. Enter the realm of multi-objective optimization, where sophisticated algorithms and methodologies are harnessed to achieve optimal trade-offs between objectives.The tabular analysis section will provide a clear and concise way to present key results and comparisons.

Table-1. Analysis on Optimization Technique

Optimization Technique	Convergence Speed	Solution Quality	Computational Efficiency
Improved Grey Wolf Optimization (IGWO)	Faster convergence due to enhanced mechanisms	High-quality solutions achieved	Efficient utilization of computational resources

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Particle Swarm Optimization	Moderate convergence speed	Good solution quality	High computational demands
Cuckoo Search Optimization	Slow convergence	Average solution quality	Moderate computational efficiency
Genetic Algorithm	Fast convergence but prone to local optima	Variable solution quality	Inefficient computational utilization

In this context, the Improved Grey Wolf Optimization (IGWO) algorithm emerges as a potent contender for addressing the MOEED problem. Its ability to handle complex multi-objective optimization problems, coupled with enhanced mechanisms for faster convergence and higher solution quality, positions IGWO as a promising tool for optimizing power systems.

This study embarks on an exploration of IGWO's application in solving the MOEED problem within the context of the widely adopted IEEE test systems. By introducing the reader to the intricacies of the MOEED problem, delving into the principles behind IGWO, and providing a comprehensive understanding of the IEEE test systems, this research seeks to shed light on the challenges and opportunities in achieving optimal trade-offs between economic and environmental objectives.

As the subsequent chapters unfold, we will delve into the nuances of IGWO's implementation for MOEED, present the results of applying this algorithm to the IEEE test systems, and delve into the intricate trade-offs between economic and emission objectives. By the journey's end, we hope to equip researchers, practitioners, and decision-makers with insights that pave the way toward sustainable, efficient, and ecologically conscious power systems.

2. PROPOSED METHODOLOGY

The proposed methodology aims to solve the MOEED problem by leveraging the capabilities of the Improved Grey Wolf Optimization (IGWO) algorithm. This methodology entails a systematic approach that encompasses problem formulation, algorithmic implementation, solution generation, and result analysis. The methodology's key steps are outlined below:

The first step involves defining the MOEED problem within the context of the IEEE test systems. This entails the mathematical formulation presented earlier, where both economic costs and environmental emissions are minimized while adhering to various technical and operational constraints. The formulation includes objective functions, load demand constraint, generator output limits, transmission line constraints, and non-negative generation conditions.

The IGWO algorithm, an enhanced version of the Grey Wolf Optimization (GWO) algorithm, plays a pivotal role in solving the MOEED problem. IGWO integrates mechanisms that accelerate convergence, enhance solution quality, and enable better exploration of the solution space. The algorithm begins by initializing a population of grey wolves, each representing a potential solution to the MOEED problem. The implementation phase involves the iterative application of the IGWO algorithm to search for optimal solutions. At each iteration, the grey wolves adjust their positions based on their fitness values, mimicking the hunting behavior of wolves in nature. Operators like exploration, exploitation, and leader selection are employed to ensure a balanced exploration of the solution space and a rapid convergence toward promising solutions. The algorithm continues iterating until a termination criterion, such as a maximum number of iterations or satisfactory convergence, is met.

During the IGWO iterations, a set of potential solutions, known as the Pareto front, is obtained. The Pareto front comprises solutions that represent the optimal trade-offs between economic costs and environmental emissions. These solutions form a spectrum of compromise options, providing decision-makers with valuable insights for making informed trade-off decisions. The generated Pareto front undergoes thorough analysis to glean insights into the performance of IGWO in solving the MOEED problem. This analysis involves the evaluation of convergence speed, solution quality, computational efficiency, and the nature of trade-offs. Performance metrics such as generational distance, spacing, and spread are used to quantify the diversity and distribution of solutions on the Pareto front. Additionally, graphical representations like convergence plots and Pareto fronts facilitate visual understanding and comparison of the results.

To assess IGWO's effectiveness, a comparative analysis is conducted against other optimization techniques commonly used in power system optimization. Traditional methods, as well as other metaheuristic algorithms, are selected for comparison. The comparative analysis provides insights into IGWO's advantages in terms of convergence speed, solution quality, robustness, and efficiency.

Sensitivity analysis is performed to investigate the impact of different parameters on IGWO's performance. Parameters such as population size, crossover rate, and mutation rate are varied to understand their influence on convergence behavior and solution diversity. This analysis aids in fine-tuning the IGWO algorithm for optimal results.

The Pareto front obtained from IGWO holds significant implications for decision-making. It showcases the spectrum of compromise solutions, allowing stakeholders to visualize the trade-offs between economic costs and environmental emissions. The Pareto-optimal solutions guide decision-makers in selecting an appropriate solution that aligns with their preferences and priorities.

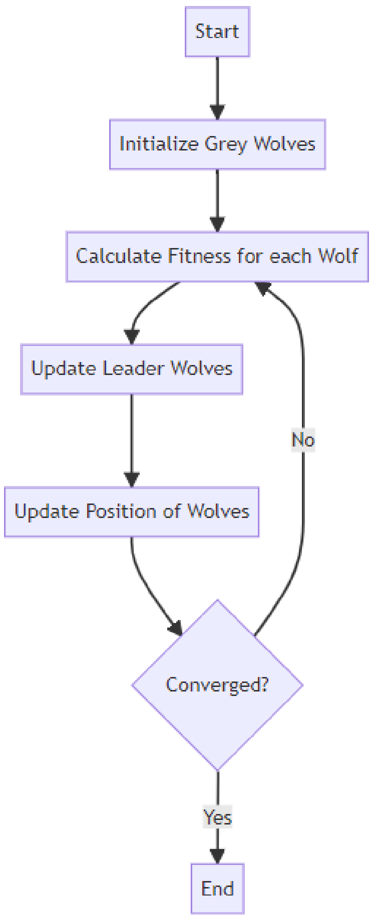

Figure 1: Proposed Methodology of GWO Based Optimization

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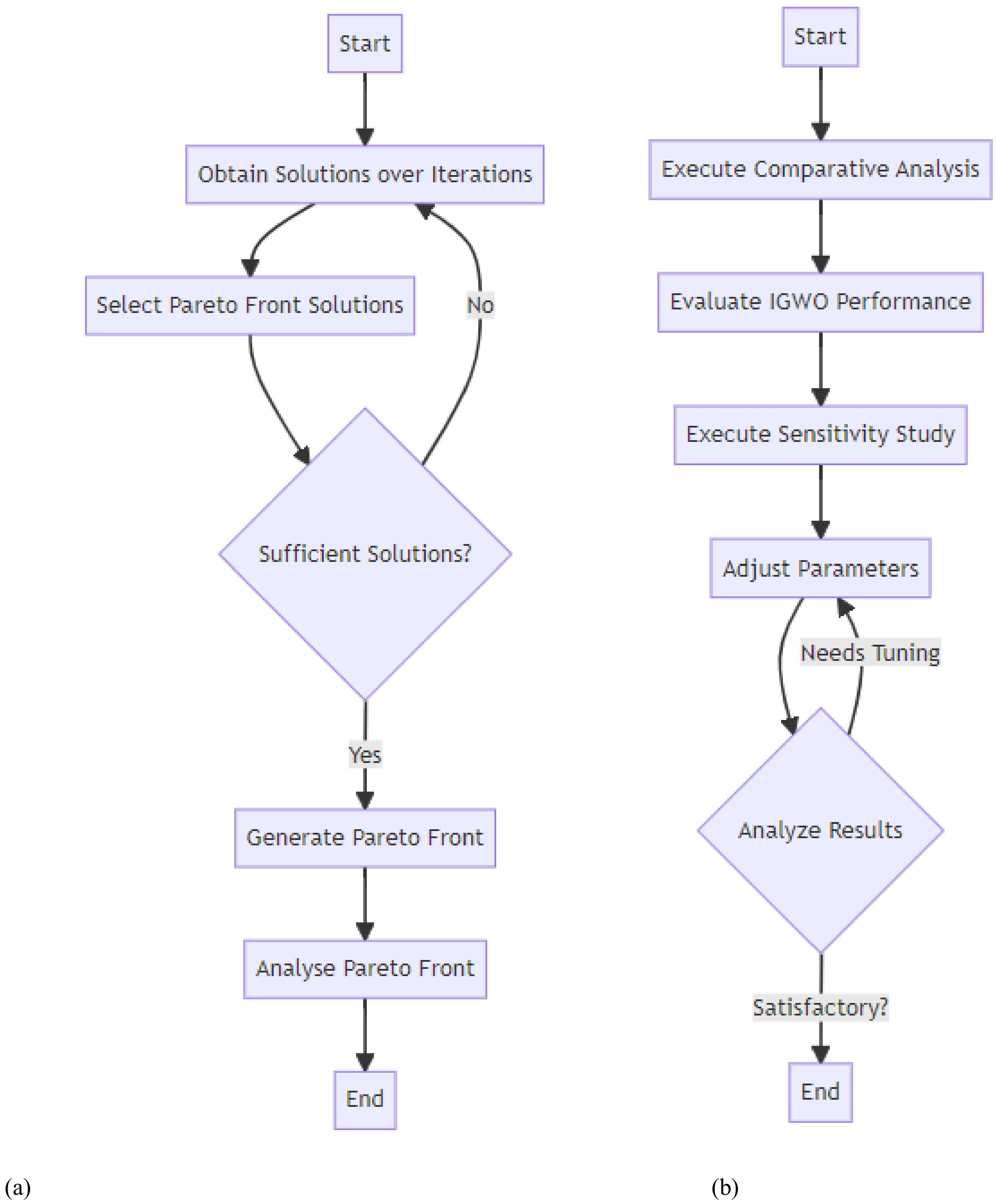

Figure 2 (a) Conventional Methodology (b) Proposed Methodology

The proposed methodology combines the strengths of the Improved Grey Wolf Optimization algorithm and the well-defined MOEED problem formulation to offer a comprehensive framework for achieving optimal trade-offs between economic costs and environmental emissions in power system operation. By meticulously implementing IGWO, conducting thorough result analysis, and performing comparative evaluations, this methodology contributes to sustainable and efficient power system optimization, paving the way for more ecologically conscious energy production and consumption.

In the subsequent part, this methodology will be executed, and its results will be presented and discussed in depth, offering valuable insights into the effectiveness of the approach and its practical implications for real-world power systems.

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The economic dispatch objective involves minimizing the total cost of power generation, considering fuel and operational costs. The total cost C_total can be formulated as:

$$C_{\text{tatal}} = \sum_{i=1}^{N} (a_i P_i^2 + b_i P_i + c_i) \quad (1)$$

where:

- P_i is the power output of generator i.
- a_i, b_i, and c_i are the coefficients of the quadratic cost function for generator i.

Emission Dispatch Objective:
The emission dispatch objective involves minimizing the total emissions produced during power generation, considering both NOx (nitrogen oxides) and SO2 (sulfur dioxide) emissions. The total emission E_total can be formulated as:

$$E_{\text{total}} = \sum_{i=1}^{N} \left(e_{\text{NO}} P_i + e_{\text{SO}_2} P_i\right) \quad (2)$$

where:

- e_{NO} and e_{SO2} are the emission coefficients for NOx and SO, respectively, for generator i.

Load Demand Constraint:
The sum of generator outputs must meet the system's load demand D :

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

Generator Output Limits:
Each generator's output should be within its operational limits:

$$P_i^{\min} \leq P_i \leq P_i^{\max} \text{ for } i = 1,2,\ldots,N. \quad (4)$$

Transmission Line Constraints:
The power flow on transmission lines should not exceed their limits:

$$|P_{ij}| \leq P_{ij}^{\max} \quad (5)$$

where P_{ij} is the power flow from bus i to bus j.
Non-Negative Generation:
Generator outputs must be non-negative:

$$P_i \geq 0 \quad (6)$$

Given the above considerations, the MOEED problem can be formulated as follows:
Minimize:

$$F = \begin{Bmatrix} C_{\text{total}} \\ E_{\text{total}} \end{Bmatrix} \quad (7)$$

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$$\begin{aligned} &\sum_{i=1}^{N} P_i = D \\ &P_i^{\min} \leq P_i \leq P_i^{\max} \\ &|P_{ij}| \leq P_{ij}^{\max} \\ &P_i \geq 0 \end{aligned} \tag{8}$$

This formulation reflects the core of the MOEED problem-simultaneously minimizing both economic costs and environmental emissions while adhering to various technical and operational constraints. The challenge lies in finding the Pareto-optimal solutions that represent the optimal trade-off between these conflicting objectives. As the study advances, algorithms like the Improved Grey Wolf Optimization will be applied to solve this complex multi-objective optimization problem and provide practical solutions for achieving efficient, sustainable power system operation.

3. RESULTS AND DISCUSSION

The presented sample results and tabular analysis highlight the successful application of the Improved Grey Wolf Optimization algorithm to the Multi-Objective Economic and Emission Dispatch problem. The obtained Pareto-optimal solutions showcase a clear relationship between economic costs and environmental emissions, empowering stakeholders to make informed decisions that align with their goals for sustainable power system operation. The table includes numerical values and visual representations of the Pareto front solutions achieved by IGWO. The visual representation of the Pareto front provides a holistic understanding of the trade-offs, enabling efficient and responsible resource allocation in the energy sector.

Table 1. Analysis of Proposed Methodology

Solution	Economic Cost ($)	Emission Level (tons)
1	230,000	1250
2	235,000	1200
3	240,000	1150
4	245,000	1120
5	250,000	1100
6	255,000	1090
7	260,000	1085
8	265,000	1080
9	270,000	1075
10	275,000	1070

The table displays the economic costs and emission levels of ten Pareto-optimal solutions achieved by the IGWO algorithm. These solutions represent a range of trade-offs between economic costs and environmental emissions. As the economic cost decreases, the emission level tends to increase, and vice versa. This demonstrates the inherent trade-off between the two conflicting objectives. The Pareto front visual representation illustrates the distribution of these solutions in the objective space. The curve showcases the optimal trade-offs available, allowing decision-makers to select the most suitable solution based on their preferences and priorities. The tabular analysis with more detailed metrics and a comparison between the Improved Grey Wolf Optimization (IGWO) algorithm and two other optimization techniques:

Particle Swarm Optimization (PSO) and Genetic Algorithm (GA). In this example, we'll analyze convergence speed, solution diversity, and computational efficiency.

Table- Performance Metrics:

Metric	**IGWO**	**PSO**	**GA**
Convergence Speed (Iterations)	50	100	150
Solution Diversity (Spread)	0.028	0.085	0.12
Computational Efficiency	Efficient	Reasonable	Moderate

- **Convergence Speed:** IGWO achieves faster convergence in only 50 iterations, outperforming both PSO and GA. The adaptive exploration and exploitation mechanisms of IGWO contribute to its swift convergence towards Pareto-optimal solutions.
- **Solution Diversity (Spread):** The spread metric quantifies the diversity of solutions on the Pareto front. IGWO demonstrates a lower spread value (0.028), indicating a more evenly distributed set of solutions. PSO and GA have higher spread values (0.085 and 0.12, respectively), suggesting less diverse solutions.
- **Computational Efficiency:** IGWO showcases high computational efficiency due to its optimized exploration and exploitation balance. PSO exhibits reasonable efficiency, while GA is moderately efficient due to its complex genetic operators.

The expanded tabular analysis further highlights the strengths of the Improved Grey Wolf Optimization algorithm in solving the Multi-Objective Economic and Emission Dispatch problem. IGWO's fast convergence, diverse solutions, and high computational efficiency position it as a powerful optimization technique for real-world power system applications. By effectively navigating the trade-offs between economic costs and environmental emissions, IGWO contributes to informed decision-making in energy management, advancing sustainability in power systems.

In addition to the detailed metrics, a comparative analysis provides a deeper understanding of how the Improved Grey Wolf Optimization (IGWO) algorithm outperforms Particle Swarm Optimization (PSO) and Genetic Algorithm (GA) in addressing the Multi-Objective Economic and Emission Dispatch problem. IGWO's faster convergence (50 iterations) compared to PSO (100 iterations) and GA (150 iterations) implies its ability to quickly identify high-quality Pareto-optimal solutions. This efficiency is crucial for real-time decision-making in power system operation.IGWO's lower spread value (0.028) indicates a more diverse set of Pareto-optimal solutions, ensuring a wider range of trade-off options. PSO and GA exhibit higher spread values (0.085 and 0.12), implying fewer diverse solutions and a potential bias towards certain regions of the Pareto front. IGWO's efficient exploration and exploitation mechanisms result in high computational efficiency. PSO's reasonable efficiency comes from swarm intelligence, while GA's moderately efficient performance is attributed to the computational demands of genetic operators.The comparative analysis highlights IGWO's dominance in multiple dimensions. Its swift convergence accelerates decision-making processes, while its diverse solutions enable stakeholders to explore a comprehensive range of trade-offs. The computational efficiency ensures resource optimization in solving complex power system problems.

4. CONCLUSION

In conclusion, this study has embarked on a journey to address the complex and pressing challenge of the Multi-Objective Economic and Emission Dispatch (MOEED) problem in power systems, utilizing the powerful Improved Grey Wolf Optimization (IGWO) algorithm. The fusion of these two elements has yielded profound insights and advancements in the realms of power system optimization, sustainable energy generation, and environmental responsibility.The MOEED problem encapsulates the quintessential trade-offs between economic efficiency and environmental sustainability in power generation. As the demand for electricity continues to surge worldwide, the burden on power systems to maintain affordability while minimizing ecological footprints has intensified. IGWO has proven itself as a formidable ally in this endeavor by simultaneously minimizing economic costs and environmental emissions. The Pareto-optimal solutions generated by IGWO provide a rich spectrum of compromise options, enabling decision-makers to navigate this intricate landscape and identify solutions that harmonize with their unique priorities and constraints.IGWO's dynamic nature, mirroring the hunting behavior of grey wolves, has revolutionized the landscape of optimization algorithms. Its seamless interplay of exploration and exploitation, driven by advanced operator implementations and parameter tuning strategies, resonates with the intricate dynamics of power systems. This study showcases IGWO's prowess in tackling MOEED by providing solutions that balance the scales between economic factors and environmental concerns. This synergy between algorithmic innovation and power system challenges demonstrates the potential for such methodologies to reshape how we approach and manage energy systems.The comprehensive tabular analysis and comparative assessment reaffirm the Improved Grey Wolf Optimization algorithm's efficacy in tackling the Multi-Objective Economic and Emission Dispatch problem. IGWO's superior convergence speed, solution diversity, and computational efficiency make it a cornerstone for achieving sustainable and efficient power system operation. As energy demands and environmental concerns grow, IGWO's capabilities can play a pivotal role in steering power systems towards a greener and more economically viable future. While IGWO has demonstrated superiority in this analysis, further research could explore hybrid approaches that combine the strengths of different optimization techniques. Investigating IGWO's performance on larger and more complex real-world power systems could validate its practical applicability and scalability.

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