

Original Article

Smart Optimization for Environmental and Economic Dispatch with Renewable Energy Integration

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Abstract - In recent years, the focus on optimal scheduling methods for Microgrids (MGs) has intensified due to their ability to efficiently manage Distributed Generation (DG) over varying time intervals. The intermittent nature of renewable energy sources like wind and solar creates significant challenges for economic dispatch within MGs, as their unpredictability complicates coordination among energy sources. This paper presents a novel, comprehensive framework for multi-objective optimal dispatch in MGs, considering both ecological and economic factors. The framework integrates various generating units, including Photovoltaic (PV) systems, Wind Turbines (WT), Microturbines (MT), Fuel Cells (FC), and Battery Storage (BT) systems. To address the complexities of balancing multiple objectives and the stochastic nature of renewable energy, the research aims to develop a feasible multi-objective optimal dispatch strategy that improves MG operations by making them faster, more stable, and more efficient in convergence. Advanced optimization techniques, particularly intelligent algorithms, are utilized within a robust simulation environment to tackle the challenges. The study develops and partially tests a mathematical model for multi-objective optimal dispatch, facilitating dynamic parameter calculations to ensure efficient system operations despite renewable energy complexities. This research demonstrates the potential for a highly efficient, sustainable MG dispatch system using intelligent optimization, providing insights for future experimental implementations and refinements.

Keywords - Distributed generations, Fuel cells, Microgrid, Photovoltaic cells.

1. Introduction

The economic dispatch problem in electrical power generation is intended to determine the optimal output level of active generating units to satisfy the required demand while respecting the system's limitations. Microgrids (MGs) provide practical approaches to diverse power system difficulties by incorporating both conventional and sustainable energy sources, such as Combined Heat and Power (CHP) facilities and Distributed Energy Resources (DER). This is accomplished by optimizing the layout of the power grid and integrating demand response from the load side into the conventional economic dispatch model for power generation. Various sub-goals with varying degrees of priority are proposed to adequately capture the multifarious aspects of monetary outlay, ecological considerations, and the reliability of the power supply. Reducing operating costs is essential for achieving cost-effective microgrid distribution. Power equilibrium equation limitations, component operation procedure constraints, energy storage constraints, and thermal

energy storage constraints are all accounted for in the analysis. Economic dispatch and voltage regulation are simultaneously attained through a dual-tier control strategy. There is a lot of variation in the effectiveness of dispatching due to the temporal dynamics of reaction times across various load-side dispatching resources. As a result, there is an opportunity to maximize benefits from both the generation and load sides through the strategic deployment of dispatching mechanisms. A large range of different operation combinations can be used to carry out the algorithm. A distribution network's key component is efficient and impregnable dispatching that supports its operational framework. The issue at hand is the ecologically constrained economic dispatch dilemma, which is both complicated and intricate. To solve this problem, we must optimize numerous nonlinear objectives within a set of restrictions. Designing a thorough system that successfully harmonizes the complex interplay between emissions and energy costs is critical. Many approaches are taken to address the difficulties of emissions and economic dispatch. To solve



this problem, we factored in a wide range of potential price increases. Microgrids are small-scale electrical networks used to power residential areas with low energy demand. They can provide customers various benefits like increased dependability, cost savings, lower carbon footprints, and renewable energy sources. Microgrids can potentially reduce environmental impacts caused by conventional, centralized power generation while simultaneously promoting and integrating Renewable Energy Sources (RES). Xiaoyan Ma et al. (2022) examined costs related to carbon emissions, system management, equipment depreciation, microgrid integration, and time-of-use tariffs, highlighting the environmental benefits of renewable energy. S. Vasanthakumar et al. (2015) discussed how micro-energy grids optimize energy use by integrating cooling, heating, and power generation technologies.

Manzoor Ellahi et al. (2020) highlighted the unpredictability of power output in microgrids, which poses safety and stability challenges for effective energy management. Xiaotong Song et al. (2020) demonstrated a method to simplify multi-objective economic emission dispatch problems into single-objective issues using price penalty factors. Siddharth Singh et al. (2020) addressed the multi-objective, nonlinear economic dispatch problem under environmental constraints, proposing various strategies involving Price Penalty Factors (PPF) to balance generation costs and emissions. Donglei Sun et al. (2020) proposed an approach to address energy systems' operational, economic, and environmental issues through multi-objective optimization strategies like economic dispatch [1-6]. Mokhtar Said et al. (2022) have analyzed an algorithm for Integrating RESs into the electricity grid. This complex task must be accomplished to minimize toxic gas emissions and reduce heat transfer costs. This complex procedure needs to be carried out within the framework of the system's many restrictions. Each of the aforesaid algorithms uses a two-stage search strategy to find the best solution in a given search space. Their sole methodological interest is in population growth and change. An extensive search on a worldwide and national scale. Hourly granular meteorological data is used pragmatically to achieve dynamic coordination between conventional power plants and Renewable Energy Sources (RESs) [7]. Using a consensus algorithm, Liu et al. present a novel, completely distributed economic dispatch technique for DC microgrids. Their method provides decentralized control, improving the efficiency and stability of the grid. This study represents a major development in decentralized energy optimization techniques and microgrid management [8]. Muhammad Waleed Tahir et al. (2022) have presented an innovative strategy for efficient energy use. Economic emissions and Energy Scheduling within a network rich in renewable resources were at the heart of their concept. This cutting-edge architecture was motivated by natural optimization mechanisms seen in biology [9]. A thorough examination of the relevant literature reveals the ability to use a unique bio-

inspired algorithm to efficiently solve the complex task of the EED problem while simultaneously integrating renewable energy sources. P. Venkatesh et al. (2023) have demonstrated the algorithm for Allocating and administering the combined economic emission burdens effectively using machine learning algorithms [10]. Chao-Hsien Hsiao et al. (2021) have proposed a new technique for economically disposing of microgrids. Particle swarm optimization and the binning technique are at the heart of this approach [11]. Kanchan Pawani et al. (2021) have illustrated a new method for solving the Economic Load Dispatch problem using the Black Widow Optimization algorithm. [12] Qing Wang et al. (2019) have proposed a method that uses scenario analysis to enable the dynamic economic power dispatch of microgrids. Renewable energy has the potential to alleviate the current energy problem, but its incorporation into the grid infrastructure increases the inherent unpredictability of this type of energy. Microgrids have made great strides in reducing the strain on the traditional electrical grid from renewable energy sources [13]. Paramguru et al. (2021), The Emperor Penguin Optimization Algorithm is used to integrate microgrids with wind energy in order to solve the Economic Dispatch Problem. Their approach maximizes power generation, improving the grid's efficiency and using renewable energy sources. This study advances solutions for sustainable energy management in power systems [14]. Zhu et al. (2020) have used a comprehensive typical scenario set to offer a stochastic economic dispatching technique for active distribution networks. Their method increases grid efficiency and resilience by introducing uncertainty. This research offers a useful approach for maximizing power distribution in dynamic and unpredictable contexts [15].

Venkatesh and Visali suggest using machine learning and soft computing techniques to improve power system security. Through the utilization of these sophisticated techniques, they provide creative approaches to risk reduction and reliable power supply. This research significantly contributes to protecting power systems from possible threats and disturbances [16]. Swief, El-Amary, and Kamh (2020) have presented a comprehensive approach to energy management to address uncertainty in load and renewables integration for plug-in hybrid vehicles. Their creative strategy promises increased dependability and sustainability, which makes it a noteworthy addition to the fields of energy optimization and environmentally friendly transportation [17, 18]. Das, Mukherjee, and Das (2020) have introduced the "Student Psychology Based Optimization Algorithm". This innovative method uses concepts from student psychology to solve optimization issues. The approach, described in *Advances in Engineering Software*, has a novel population-based strategy that shows promise for effective problem-solving [19]. This creative strategy maximizes electricity production from renewable sources while integrating environmental restrictions with economic dispatch. It maximizes effectiveness while minimizing environmental impact by

considering variables like emissions limitations and the availability of renewable energy. With environmental concerns mounting, this development is a big step toward sustainable energy management.

2. Problem Formation

Objective Function: This function aims to reduce overall generation costs and emissions for each Distributed Generation (DG) unit.

$$\text{Min } K(P_i) = \sum_{j=1}^n C_{g,j}(P_j) + \sum_{j=1}^n C_{e,j}(P_j) \quad (1)$$

In the MG system, 'n' is the number of DG units. K(Pj) is the total operating cost (\$/hr) of these units. Cg,j is the generation cost, Ce,j is the emission cost, and Pj is the power output of the jth DG unit.

2.1. Operating and Maintenance Costs

2.1.1. Fuel Cost (FC)

$$D_f(P_j) = K_{f,j} \times P_j \quad (2)$$

Where Pj is the output power produced by the jth DG unit, Kf,j is the fuel coefficient of the jth DG unit/kWh, and D(f,j) (Pj) is the FC of the jth DG unit/h.

2.1.2. Operating Cost

$$Y_{o,j}(P_j) = K_{o,j} \times P_j \quad (3)$$

Where Pj is the output power produced by the jth DG unit, Yo,j(Pj) is the operation and maintenance cost of the jth DG unit, and Ko,j is the operation and maintenance coefficient (\$/kWh).

2.1.3. Emission Cost

$$Q_{e,i}(P_i) = K_{o,i} \times M_e \times P_i \quad (4)$$

K(e,j) represents the emissions coefficient for the jth Distributed Generation (DG) unit per kilowatt-hour (kWh), and Qe,j(Pj) denote the emission cost for the jth DG unit per kWh. The variable I stands for the price of greenhouse gas emissions per kilogram, while Pj refers to the power output of the jth DG unit.

2.2. Constraints

2.2.1. Power Balance Constraint

$$P_D = \sum_{ni=1} P_i + P_B \quad (5)$$

Where, Pi =Active power generation of DG unit, PD = total demand, and PB = capacity of battery.

2.2.2. DG Output Limits

$$P_{i,max} \leq P_i \leq P_{i,min} \quad (6)$$

where Pi, min, Pi, and max represent the DG unit's lower and higher power limits, respectively.

2.2.3. The Operational Limitations Pertaining to the Battery

$$-PB_{max} \leq B_{min} \leq PB_{max} \quad (7)$$

PBmax represents the pinnacle of the battery's charging potential, while -PBmax signifies the utmost capacity for discharging power.

3. Student Psychology-Based Optimization (SPBO)

SPBO Students aim to be at the top of their class by performing exceptionally well on their final exams. Examination scores are used to evaluate performance.

A student is considered to be at the top of their class if they score the highest on the final exam. If you want to be the top student in your class, you need to work harder than the rest of your classmates to raise your exam scores on each topic.

If they wish to be recognized as the best of their class, pupils must excel above their peers. To succeed, they must put in more effort to master the material. They need to do well across the board to improve their final grade.

Therefore, students should make an effort in each subject if they want to improve in general. However, a student's ability, productivity, and excitement for a given subject affect how much effort they are willing to put in. It is, therefore, essential to stress that not all students may experience the same level of improvement in their exam results. Student effort depends on their personalities.

Some pupils aspire to outwork the best. Some of my classmates strive, but they also try to beat the smart kids and the best students.

Academic progress depends on effort. Students concentrate harder in subjects they love to improve their exam scores. The algorithm working procedure and mathematical analysis of student psychology were referred to and analyzed [19]. SPBO is shown in Figure 1.

4. Simulation Results and Discussion

A study that optimized the economic and ecological dispatch of a Microgrid (MG) using the Stochastic Particle Swarm Optimisation (SPBO) method is shown here. SPBO results are compared to Lagrange outcomes to determine efficacy. SPBO is best for environmental and economic dispatch. Daily MG system requirements.

The recommended Stochastic Parallel Branch and Optimization (SPBO) approach reduced the microgrid's economic power dispatch challenge's economic and emission costs. Six solar-wind generators cost the following.

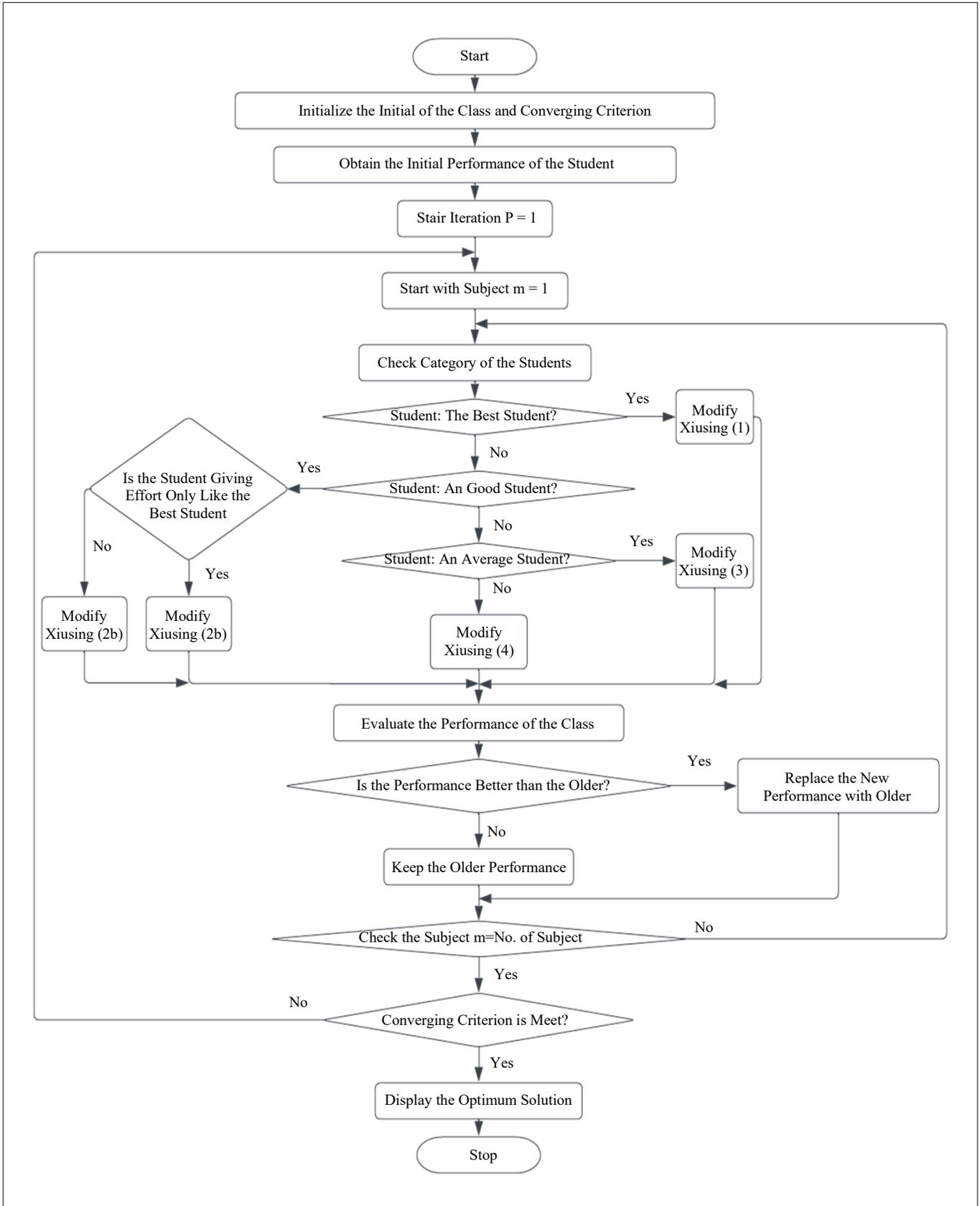


Fig. 1 Flowchart for SPBO

4.1. Case 1: Six Generating Units

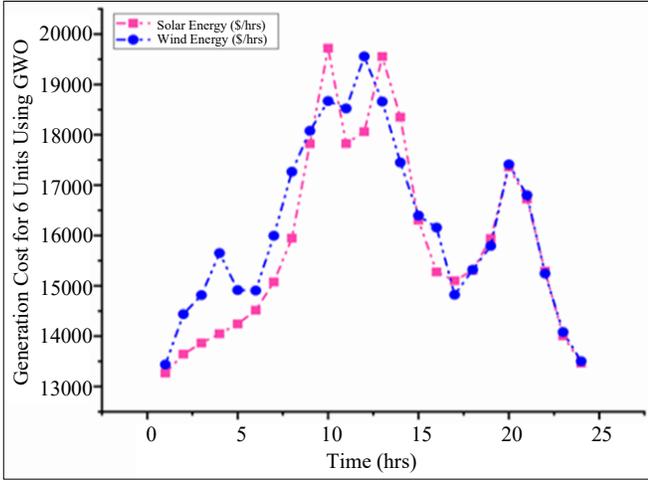


Fig. 2 Generation cost for 6 units using solar and wind energy with the GWO method

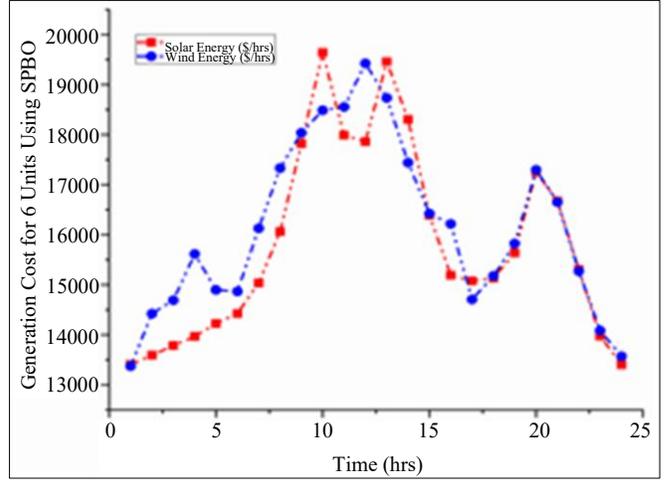


Fig. 4. Generation cost for 6 units using solar and wind energy with the SPBO method

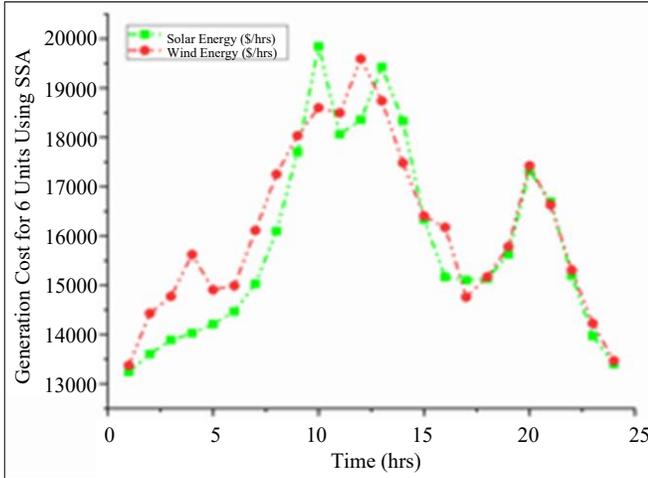


Fig. 3 Generation cost for 6 units using solar and wind energy with the SSA method

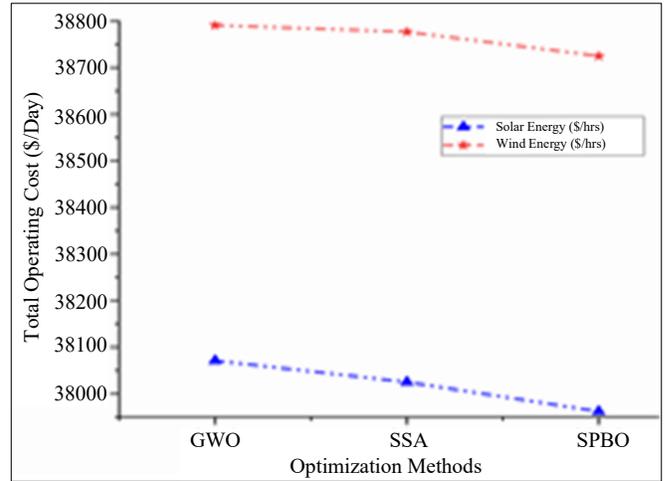


Fig. 5 The total operating cost for 6 units using solar and wind energy with the SPBO method

Table 1. Generation cost and total operation cost comparison using GWO, SSA, and SPBO for 6 generating units without RES and with RES for 24-hour demand

| Time | Without RES | | | With RES | | |
|------|-------------|-------|-------|----------|-------|-------|
| | GO | SSA | SPBO | GO | SSA | SPBO |
| 1 | 13334 | 13212 | 13216 | 13373 | 13388 | 13370 |
| 2 | 13600 | 13710 | 13597 | 14435 | 14478 | 14433 |
| 3 | 13811 | 13809 | 13876 | 14711 | 14743 | 14691 |
| 4 | 14138 | 13995 | 14100 | 15635 | 15700 | 15645 |
| 5 | 14199 | 14203 | 14258 | 14964 | 15028 | 14976 |
| 6 | 14414 | 14475 | 14535 | 14976 | 14872 | 14860 |
| 7 | 14649 | 14666 | 14642 | 16519 | 16569 | 16459 |
| 8 | 14870 | 14935 | 14816 | 18440 | 18407 | 18413 |
| 9 | 16043 | 16422 | 16230 | 19722 | 19640 | 19671 |
| 10 | 16900 | 17009 | 16809 | 21323 | 21366 | 21276 |

| | | | | | | |
|----|-------|-------|-------|-------|-------|-------|
| 11 | 17431 | 17330 | 17327 | 19104 | 19063 | 18959 |
| 12 | 17878 | 17723 | 17736 | 19764 | 19705 | 19786 |
| 13 | 17543 | 17503 | 17312 | 20824 | 20797 | 20784 |
| 14 | 16675 | 16614 | 16628 | 19399 | 19266 | 19300 |
| 15 | 15668 | 15687 | 15712 | 17177 | 17163 | 17113 |
| 16 | 14842 | 14844 | 14826 | 16543 | 16509 | 16595 |
| 17 | 14398 | 14373 | 14442 | 15503 | 15498 | 15414 |
| 18 | 14972 | 15172 | 15058 | 15371 | 15440 | 15470 |
| 19 | 15739 | 15696 | 15675 | 15698 | 15692 | 15759 |
| 20 | 17501 | 17290 | 17242 | 17548 | 17284 | 17328 |
| 21 | 16700 | 16653 | 16762 | 16639 | 16637 | 16590 |
| 22 | 15294 | 15217 | 15220 | 15239 | 15258 | 15245 |
| 23 | 14015 | 14006 | 14002 | 14099 | 14098 | 14161 |
| 24 | 13516 | 13401 | 13406 | 13470 | 13506 | 13514 |

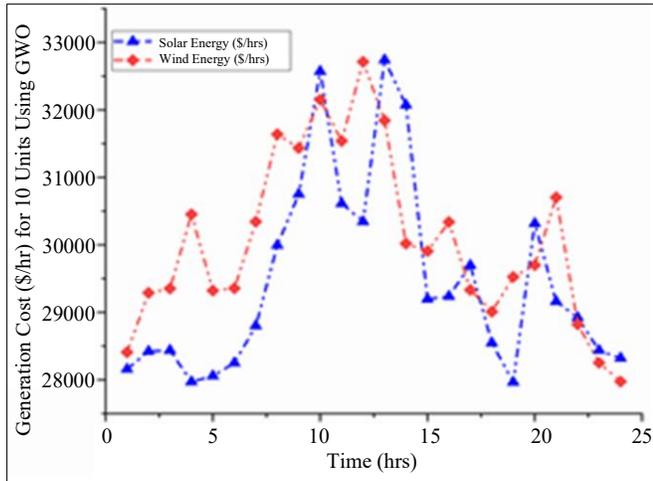


Fig. 6 Generation cost for 10 units with solar and wind energy using the GWO method

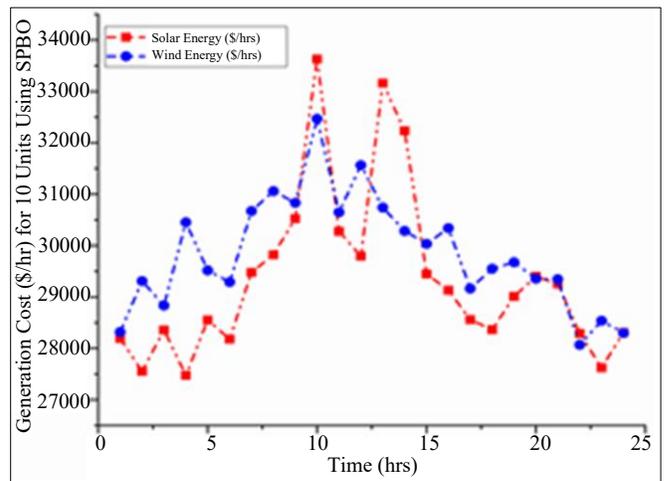


Fig. 8 Generation cost for 10 units with solar and wind energy using the SPBO method

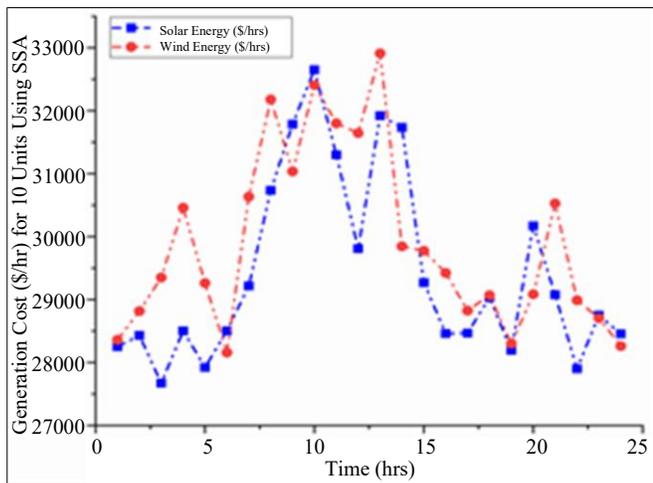


Fig. 7 Generation cost for 10 units with solar and wind energy using the SSA method

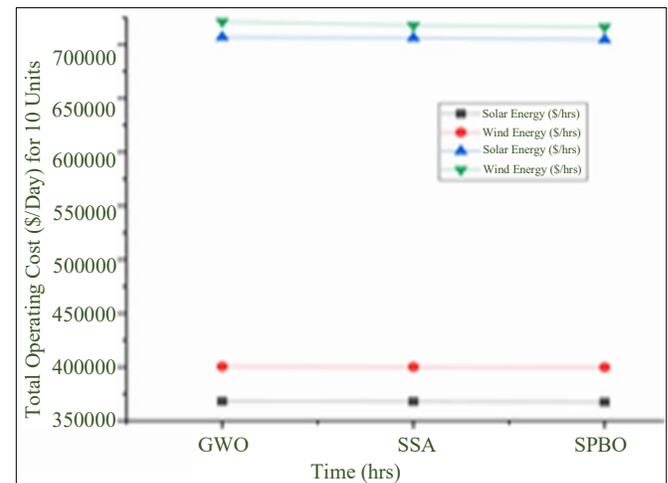


Fig. 9 The total operating cost for 10 units using renewable energies with optimization methods for 24-hour demand

Table 2. Comparative analysis of optimization techniques for generation cost and total operation cost of 10 generating units with and without RES for 24-hour demand

| Time | Without RES | | | With RES | | |
|------|-------------|-------|-------|----------|-------|-------|
| | GWO | SSA | SPBO | GWO | SSA | SPBO |
| 1 | 27984 | 28184 | 27880 | 28308 | 28441 | 28099 |
| 2 | 28345 | 27626 | 28302 | 29226 | 29148 | 28840 |
| 3 | 28598 | 28449 | 28628 | 29432 | 29557 | 29511 |
| 4 | 28689 | 27706 | 27929 | 30496 | 30414 | 29888 |
| 5 | 28817 | 28761 | 27437 | 29443 | 29523 | 29475 |
| 6 | 27660 | 28883 | 28625 | 29158 | 29379 | 28321 |
| 7 | 28583 | 28468 | 27975 | 30890 | 31079 | 31153 |
| 8 | 29004 | 28592 | 29129 | 33250 | 33422 | 33365 |
| 9 | 29302 | 29260 | 28416 | 33847 | 34220 | 34031 |
| 10 | 30745 | 30272 | 29010 | 35182 | 35558 | 34995 |
| 11 | 30846 | 30748 | 29164 | 31834 | 31225 | 31567 |
| 12 | 30398 | 30545 | 29940 | 31746 | 33107 | 31932 |
| 13 | 29966 | 30185 | 30431 | 34636 | 33595 | 34725 |
| 14 | 28819 | 28989 | 29520 | 32654 | 32853 | 32791 |
| 15 | 28907 | 29012 | 28395 | 31007 | 30469 | 30032 |
| 16 | 28603 | 28579 | 29388 | 30988 | 30440 | 30023 |
| 17 | 27803 | 28117 | 27691 | 29916 | 29766 | 30083 |
| 18 | 29154 | 28696 | 28281 | 29117 | 29738 | 29233 |
| 19 | 29586 | 29307 | 29247 | 29187 | 28306 | 28643 |
| 20 | 31079 | 29236 | 30572 | 30639 | 29968 | 31031 |
| 21 | 30451 | 29019 | 29196 | 29244 | 29266 | 28884 |
| 22 | 28441 | 29313 | 27990 | 29264 | 28711 | 28276 |
| 23 | 28342 | 28453 | 28699 | 28062 | 28602 | 27953 |
| 24 | 28333 | 28277 | 28203 | 28395 | 28328 | 28250 |

4.2. Case 2: Ten Generating Units

Figures 6 to 8 explain the individual solar energy and wind energy utilized to support the 10 generating units by using optimization algorithms (i.e., GWO, SSA, and SPBO) for 24-hour demand.

Optimization (SPBO) solution yields superior outcomes and adeptly resolves the intricate Combined Economic and Emission Dispatch Problem. In further work, valve point load effects, uncertain constraints, and energy storage devices can be incorporated into analyzing the optimal allocation of generators.

5. Conclusion

Using the Price Penalty Factor (PPF), the Grey Wolf Optimization (GWO), the Sparrow Search Algorithm (SSA), and the Student Psychology Based Optimization (SPBO) have all been used to solve the Combined Economic and Emission Dispatch (CEED) problem for a 24-hour demand. By conducting a comprehensive analysis of the total cost associated with various methods for meeting 24-hour demand. This paper will use the GWO, SSA, and SPBO algorithms to address the CEED problem by implementing the price penalty factor.

The price penalty factor for the min/max approach has proven to yield optimal outcomes when successfully resolving the CEED problem. The outcome derived from the SPBO shall be juxtaposed with the GWO and SSA for comprehensive analysis and evaluation. The proposed SPBO method demonstrates superior performance in optimizing the total fuel cost for the CEED problem, surpassing both GWO and SSA. Henceforth, the proposed Strategic Performance Boosting

Nomenclature

| | |
|----------------|--|
| $K(P_i)$ | Total operating cost (\$/hrs) |
| $C_{g,j}$ | Cost of generation (kW) |
| $C_{e,j}$ | Cost of Emission |
| P_j | Power output produced at the j^{th} bus(kW) |
| $K_{f,j}$ | Fuel coefficient of the j^{th} DG unit/kWh |
| $Y_{o,j}(P_j)$ | operation and maintenance cost of the j^{th} DG unit |
| $K_{o,j}$ | Operation and Maintenance coefficient (\$/kWh) |
| $K_{e,j}$ | Emissions coefficient at j^{th} DG unit/kWh |
| $Q_{e,j}(P_j)$ | Emission cost of the j^{th} DG unit/kWh |
| X_{best} | best student mark obtained |
| X_j | Randomly selected J^{th} student |
| T_{amb} | Ambient temperature ($^{\circ}C$ or K) |
| V_{oc} | Open-circuit voltage (V) |
| ELD | Economic Load Dispatch |

| | |
|-----|--------------------------------|
| ED | Emission Dispatch |
| EED | Economic and Emission Dispatch |
| DER | Distributed Energy Resources |

| | |
|------|---------------------------------------|
| GWO | Gray Wolf Optimization |
| SSA | Sparrow Search Algorithm |
| SPBO | Student Psychology based optimization |

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