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Research Article

The Optimal Unit Dispatch Program for Thermal Units in Power Systems with the Presence of a High-Penetration Wind Farm and Flexible Loads

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Abstract

In this paper, a stochastic model for economic dispatch (ED) in power systems with the presence of renewable energy sources and flexible loads is proposed, which also considers the associated uncertainties. This model is scenario-based and utilizes Monte Carlo simulation to determine scenarios with scenario-specific weighting factors. To solve the optimization problem, a new hybrid algorithm called hLSA-PSO is developed, in which the parameters of the Particle Swarm Optimization (PSO) algorithm are tuned by the Lightning Search Algorithm (LSA). The performance of this algorithm is validated by comparing the results obtained from solving benchmark functions with GGO, PSO, and LSA algorithms. Simulation studies show that the proposed model is executed in three different scenarios: without considering uncertainty and load response, with uncertainties but without the participation of flexible loads, and with both factors considered. The results showed that considering uncertainties increased operational costs by 2.6%, and also, due to uncertainty, the share of wind resources in load supply decreased. On the other hand, the participation of flexible loads reduced generation during peak hours and lowered costs. The hLSA-PSO algorithm outperformed the other methods in all cases.

Keywords: Flexibility, Economic dispatch, Uncertainty, Wind farm.

Highlights

- A stochastic model for economic dispatch (ED) in power systems with the presence of renewable energy sources and flexible loads is proposed.
- This model is scenario-based and utilizes Monte Carlo simulation to determine scenarios with scenario-specific weighting factors.
- To solve the optimization problem, a new hybrid algorithm called hLSA-PSO is developed.

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1. Introduction

The supply of electrical energy by power generation units at the lowest cost has always been a crucial issue in power systems. This challenge has become more complex due to technical and economic constraints, as well as the growing demand for electricity. Traditional load distribution methods are often inefficient and uneconomical. With the increasing number of generators and system complexity, economic dispatch (ED) problems have become more complicated, making conventional methods such as Newton and Lambda unsuitable for solving these problems [1]. Additionally, given the energy crisis and environmental concerns, renewable sources such as wind power have gained attention as viable alternatives to fossil fuels. However, wind power generation is highly uncertain due to the random variations in wind speed, which must be considered in power system studies. Uncertainties in various parameters, including load demand and wind farm power output, can significantly impact results, necessitating accurate modeling to enhance power system performance [2-3]. Various methods have been proposed for unit commitment and dispatch planning in power systems. Traditional ED methods include linear programming (LP) [4], nonlinear programming (NLP) [5], and dynamic programming (DP) [6]. In [7], a hybrid ED approach combining LP and mixed-integer linear programming (MILP) was introduced for managing power generation units. In [8], the MILP model was utilized to optimize power generation through demand response programs (DRP) to reduce peak demand. Reference [9] focused on maximizing the revenue of generation units and distributed energy resources (DER) using DRP. Heuristic algorithms have also been widely applied in ED problems. In [10], the Grey Wolf Optimizer (GWO) was proposed for ED in power grids, considering both operational and investment costs. The Whale Optimization Algorithm (WOA) was employed in [11] to minimize system costs and improve the objective function. Reference [12] introduced a fuzzy logic-based ED approach to reduce load fluctuations in networks with distributed generation (DG).

2. Innovation and contributions

Based on the conducted studies, it is essential to examine the impact of flexible loads and account for uncertainties in power system operation. Therefore, this paper proposes a probabilistic model for economic dispatch (ED) in power systems with wind renewable farms, considering the participation of flexible loads in demand response programs (DRP). To solve the optimization problem, a novel hybrid heuristic algorithm, hLSA-PSO, is introduced, which combines Particle Swarm Optimization (PSO) and Lightning Search Algorithm (LSA). In the proposed optimization approach, the parameters of the PSO algorithm are fine-tuned using the LSA algorithm to enhance the accuracy of the economic dispatch solution under uncertainty conditions. The key innovations of this paper include:

- Introducing a probabilistic economic dispatch model for power systems in the presence of wind renewable farms.
- Considering the participation of flexible loads in both the DRP program and optimal economic dispatch.
- Proposing the hybrid hLSA-PSO algorithm, which combines PSO and LSA, to optimally solve the economic dispatch problem.

3. Materials and Methods

Flexibility is a key aspect of any energy system, as it enables the system to effectively adapt to uncertainties while maintaining stability and cost efficiency. Load flexibility refers to the power system's capacity to dynamically adjust and balance electricity supply and demand in response to changing energy market conditions. On the other hand, uncertainty is an inherent part of power system studies, and neglecting it can compromise the reliability of results. Identifying and appropriately modeling sources of uncertainty can help mitigate their effects and enhance system performance. The key sources of uncertainty in economic dispatch (ED) programs considered in this paper include load demand uncertainty, wind farm power generation uncertainty, and energy price uncertainty in the market. Various models have been proposed for load uncertainty modeling, among which the normal probability density function (PDF) is a suitable approach for representing load variations. The performance of optimization algorithms is highly dependent on their parameters. Improper parameter selection can lead to lack of convergence or cause the algorithm to get trapped in local optima. In this paper, an innovative algorithm called hLSA-PSO is proposed to solve the ED problem. This hybrid algorithm combines Lightning Search Algorithm (LSA) and Particle Swarm Optimization (PSO). In hLSA-PSO, the parameters of the PSO algorithm are optimally adjusted in each iteration using the LSA algorithm, improving its performance and ensuring efficient convergence. In this paper, a standard power system consisting of ten thermal generation units along with two wind farms has been selected for simulations in this section. The single-line diagram of the studied power system is shown in Figure I.

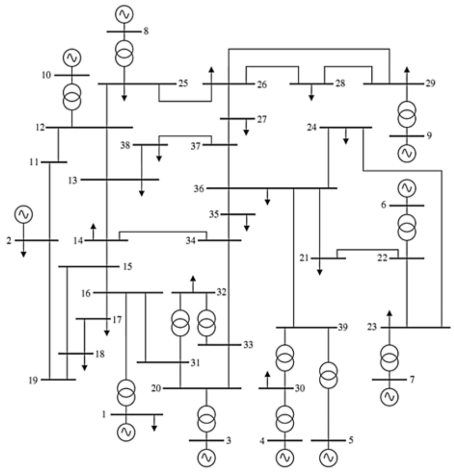

Figure I. The single-line diagram of the power system under study

4. Results and Discussion

Economic Dispatch (ED) is performed in three stages. In the first stage, ED is executed without considering uncertainties and demand response programs (DRP). In the second stage, uncertainties are incorporated into the ED model, but DRP is not considered. Finally, in the third stage, ED is conducted while accounting for both uncertainties and DRP.

In the first stage, the economic dispatch (ED) problem is solved without considering uncertainties or demand response programs (DRP). To solve the ED problem, the proposed hLSA-PSO algorithm is utilized alongside Particle Swarm Optimization (PSO), Lightning Search Algorithm (LSA), Grey Wolf Optimizer (GWO), Genetic Algorithm (GA), and Whale Optimization Algorithm (WOA). The convergence trends of these optimization algorithms are illustrated in Figure II.

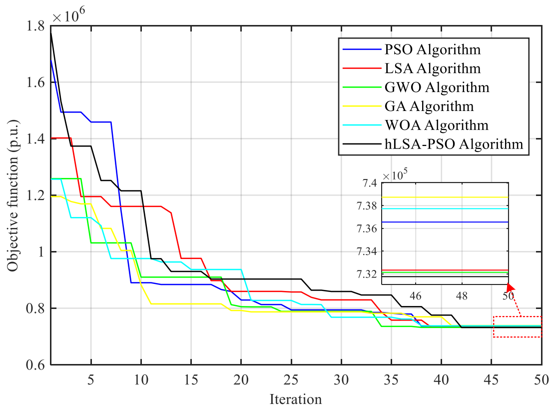

Figure II. Convergence process of optimization algorithms in Section One

The optimization results indicate that the proposed hLSA-PSO algorithm has converged to a lower value compared to other optimization algorithms. The operational cost when using the schedules provided by the hLSA-PSO algorithm is estimated to be $731,765. When applying the schedules suggested by the PSO, LSA, GWO, GA, and WOA algorithms, the operational costs were calculated as $736,561, $732,341, $732,145, $738,743, and $737,736, respectively.

In the second part of the simulations, economic load dispatch is performed considering the uncertainties of load and wind farm, while neglecting the participation of loads in the Demand Response Program (DRP). Similar to the previous section, the PSO, LSA, GWO, GA, and WOA algorithms, along with the proposed hLSA-PSO algorithm, were used to solve the load dispatch problem. The convergence trends of the optimization algorithms are shown in Figure III.

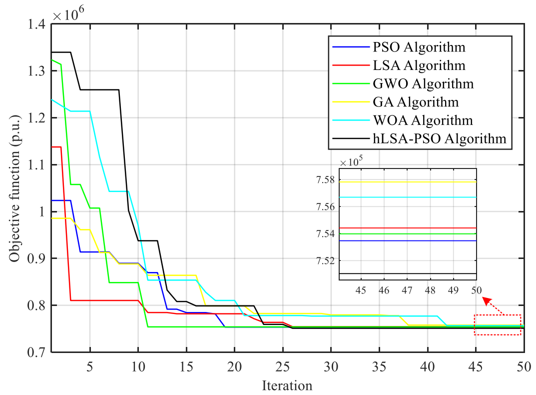

Figure III. Convergence process of optimization algorithms in Section Two

In this section, the operational cost when using the proposed hLSA-PSO algorithm is found to be lower than that of other optimization algorithms. The objective function values for the PSO, LSA, GWO, GA, and WOA algorithms are calculated as $753,471, $754,418, $753,981, $757,823, and $756,693, respectively. The operational cost when using the hLSA-PSO algorithm is obtained to be $751,038. The results indicate a 2.6% increase in operational costs when considering uncertainties in the power system. In the third part of the simulations, economic load dispatch in the power system is performed considering the uncertainties of load and wind farm, as well as the participation of responsive loads in the Demand Response Program (DRP). The convergence trends of the optimization algorithms in this section are shown in Figure IV. The results indicate a reduction in costs compared to the previous part of the simulations. The reason for this is the participation of loads in the Demand Response Programs. By reducing the peak load hours and providing rewards to responsive loads, operational costs can be decreased. The objective function value when using the proposed hLSA-PSO algorithm is obtained to be $743,461, which is lower than that of other algorithms. Meanwhile, the PSO, LSA, GWO, GA, and WOA algorithms converged to values of $745,677, $744,023, $747,843, $748,027, and $744,189, respectively. The operational costs indicate that considering the Demand Response Program results in a 1.35% reduction in costs.

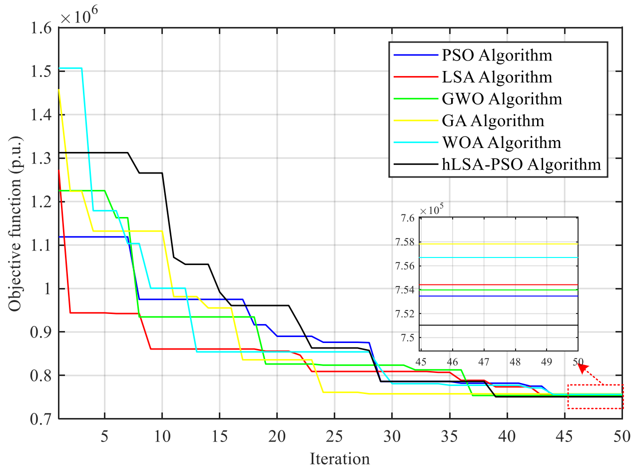

Figure IV. Convergence process of optimization algorithms in Section Three

5. Conclusion

In this paper, a stochastic model for economic dispatch (ED) in power systems with renewable energy farms is proposed, considering uncertainties and the participation of flexible loads in demand response programs (DRP). The proposed model is scenario-based, where each selected scenario, generated using the Monte Carlo mechanism, is assigned a specific weighting factor. To solve the optimization problem, a novel hybrid algorithm called hLSA-PSO is introduced, in which the parameters of the Particle Swarm Optimization (PSO) algorithm are tuned using the Lightning Search Algorithm (LSA). The accuracy and effectiveness of the proposed algorithm are validated by solving standard benchmark functions and comparing the results with optimization algorithms such as Grey Goose Optimization (GGO), PSO, and LSA. In the second part, the performance of the proposed algorithm in solving the ED problem is evaluated in three stages. In the first stage, ED is solved without considering uncertainties and demand response programs. In the second stage, uncertainties are incorporated into the ED model, but DRP is not considered. Finally, in the third stage, ED is performed while accounting for both factors. Simulation results indicate a 2.6% increase in operational costs when uncertainties are considered in the power system. Due to these uncertainties, wind farms contribute less to meeting the network load. On the other hand, the participation of loads in the demand response program reduces power generation during peak hours, leading to lower operational costs. Furthermore, in all stages, the proposed hLSA-PSO algorithm outperforms other algorithms in solving the problem and reducing operational costs.

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References

[1] F. Marzbani and A. Abdelfatah, “Economic dispatch optimization strategies and problem formulation: A comprehensive review,” Energies, vol. 17, no. 3, p. 550, 2024.

[2] S. Bhavsar et al., “Stochastic economic dispatch of wind power under uncertainty using clustering-based extreme scenarios,” Electric Power Systems Research, vol. 229, p. 110158, 2024.

[3] M. Dehvan et al., “Economic Dispatch Optimization in Multi-Area Power Distribution Considering Wind Farms and Hydro Power Plants,” Mehrnoosh, 2024.

[4] M.R. Gholami Dehbalaee, G.H. Shaeisi, and M. Valizadeh, “A novel exclusive binary search algorithm to solve the nonlinear economic dispatch problem,” Journal of Energy Management and Technology, vol. 4, no. 3, pp. 48-56, 2020.

[5] B. Postolov and A. Iliev, “New metaheuristic methodology for solving security constrained hydrothermal unit commitment based on adaptive genetic algorithm,” International Journal of Electrical Power & Energy Systems, vol. 134, p. 107163, 2022.

[6] J. Zou, S. Ahmed, and X.A. Sun, “Multistage stochastic unit commitment using stochastic dual dynamic Putz, D., Schwabeneder, D., Auer, H. and Fina, B., 2021. A comparison between mixed-integer linear programming and dynamic programming with state prediction as novelty for solving unit commitment,” International Journal of Electrical Power & Energy Systems, vol. 125, p. 106426, 2018.

[7] X. Zhang et al., “Short-circuit current constrained unit commitment and transmission switching model for improving renewable integration: An MILP formulation,” IET Generation, Transmission & Distribution, vol. 16, no. 9, pp. 1743-1755, 2022.

[8] Z.K. Feng et al., “A mixed integer linear programming model for unit commitment of thermal plants with peak shaving operation aspect in regional power grid lack of flexible hydropower energy,” Energy, vol. 175, pp. 618-629, 2019.

[9] M. Nozarian et al., “Hydro Thermal Unit Commitment involving Demand Response resources: a MILP formulation,” Electrical Engineering, pp. 1-18, 2022.

[10] K. Srikanth et al., “Meta-heuristic framework: quantum inspired binary grey wolf optimizer for unit commitment problem,” Computers & Electrical Engineering, vol. 70, pp. 243-260, 2018.

[11] S. Reddy K et al., “Binary whale optimization algorithm: a new metaheuristic approach for profit-based unit commitment problems in competitive electricity markets,” Engineering Optimization, vol. 51, no. 3, pp. 369-389, 2019.

[12] N.K. Navin and R. Sharma, “A fuzzy reinforcement learning approach to thermal unit commitment problem,” Neural Computing and Applications, vol. 31, no. 3, pp. 737-750, 2019.

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