



A Review of Metaheuristic Algorithms for Load Forecasting in Smart Grids

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Abstract

Smart electrical grids (SGs) have emerged to advance the management of power systems by solving issues such as voltage instability, reactive loads, power loss, and the integration of renewable energy resources. This review focuses on the applicability of metaheuristic algorithms to energy distribution systems, improve operation, and overcome the repercussions affecting the environment and overall costs. PSO, GA, and GWO have been identified for their effectiveness in dealing with the complexity of PS due to the nonlinear and dynamic nature of today's energy systems. The review also addresses the extension of methods in machine learning for enhancing load forecasting and real-time energy control, which are key factors for shifting to innovative and renewable energy systems. Based on the literature review of the state of the art over the last five years, this research highlights some achievements and limitations. It provides recommendations for further directions in advancing Smart Grid algorithms. These results highlight the use of meta-heuristics in redesigning processes that offer optimal, reliable and sustainable energy facilities.

Keywords: Metaheuristic Algorithms; Smart Grids; Energy Management Systems; Renewable Energy Integration; Load Forecasting; Optimization Techniques

1. Introduction

Due to the enhancement of challenges in the center's traditional social energy structures and improved complexity in energy administrations, the electrical Smart Grids (SGs) have come to be an innovative, creative idea in the power plans. These advanced grids rely on AI, optimization algorithms, and constant monitoring to solve fundamental operational problems. Smart Grids have revolutionized energy systems by attacking problems of voltage instability, load power factor, energy losses, and integration of distributed generation. It is an improvement in power systems that aid in improving their dependability and effectiveness while at the same time ensuring global objectives of environmental care that decrease the emission of greenhouse gases and increase the use of renewable energy [1].

Smart Grids are distinguished from their conventional counterparts in that they facilitate the real-time management of energy demand and supply at an impossible level with the others. The real-time data analysis and quadric analytics of these systems ensure that power distribution is improved, drawbacks in energy provision are reduced, and service interruptions are avoided. Furthermore, efficient prediction and load

management enhance using renewable supplies, including solar and wind Energy. They play a crucial role in countering the disadvantage of variable renewable energy sources and providing a steady energy supply. The integration of such modern technologies as smart grids in power systems evidences their significance in developing future power systems capable of enhancing unpredictable flexibility and robustness for global power systems. [2].

Smart Grids hold the key to the vision of future energy systems to serve the needful demand for efficient, resilient, more sustainable, less cost-intensive power supply structures. Subordinate systems make energy distribution a fast and productive process involving artificial intelligence, remote monitoring, and optimization algorithms. They are instrumental in both domestic and commercial contexts due to their efficiency in adapting to, and integrating with, complicating energy requirements and using renewable energy sources. Smart Grids have delivered definite scalability features and made the traditional power systems intelligent networks capable of making efficient supply and achieving significant savings. Their application demonstrates the world's willingness and ability to make energy efficiency enhancements with minimal environmental adverse effects. [3].

In his review, he focuses on trying to look at the future, the amount of information, and innovations that have been made in Smart Grid technology and the last five years in particular. Particularly, practice-oriented attention is given to optimization techniques, including Genetic Algorithm (GA), Particle Swarm Optimization (PSO), and Grey Wolf Optimization (GWO), which were applied in the fields to improve energy intensity and reduce operating costs. These algorithms have solved the problem related to energy management by predicting the energy demand accurately, allocating Energy dynamically, and running the system cost-efficiently. Moreover, using renewable energy sources, the utilization of energy storage systems has also been treated and analyzed in detail, providing viable solutions to the issues of energy uncertainty due to sharp fluctuations in energy production and consumption. Indeed, this insight brings out the essence of Smart Grids' aim to enhance energy sustainability and manage the operational issues associated with multiple sectors [4].

1.1 Scope of the Review

The review compiles key insights from recent research, addressing:

- ✓ Optimization techniques in Smart Grids can be classified as Genetic Algorithms (GA), Particle Swarm Optimization (PSO) and Grey Wolf Optimization (GWO).
- ✓ The penetration of RES in the existing power system network has given sustainability standards.
- ✓ EMS optimization and the ways to overcome difficulties at its implementation with an account of the variability of renewable power sources and demand profiles.
- ✓ Novelties in developing machine learning and artificial intelligence in load forecasting and scheduling for energy efficiency.

1.2 Metaheuristic Algorithms Relevance

The problems involving energy resource optimization are highly complicated due to the non-linearity that defines the current energy systems. Since these issues cannot be solved traditionally, several innovative solutions have been discussed, and among them, metaheuristic algorithms have been recognized as one of the most effective. These algorithms provide reliable solutions for the management and distribution of energy services and productivity enhancement without compromising cost-reduction approaches to hassling environmental effects. That is why these tools are relevant for solving problems in the world of energy systems, which is constantly changing and cannot be predicted, at least for the near future. Using such methods as PSO, GA, and GWO, metaheuristics permit accurate prognostication, efficient load sharing, and optimal resource utilization. Despite dynamic conditions, they are essential in managing the integration of renewable energy sources, supply-demand equations, and system reliability. In addition, they are computationally efficient and scale up well, hence applicable in personal energy management to large power systems. The complexities of metaheuristic algorithms have facilitated the development of Smart Grid technologies since metaheuristic algorithms offer insights into moving from conventional energy systems to innovative and sustainable systems. These algorithms support minimizing carbon footprints and improving

system robustness by managing energy flow and avoiding overreliance on fossil resources. Thus, supporting green energy transformations is important for forming sustainable, efficient, eco-friendly energy configurations worldwide. Therefore, metaheuristic algorithms do not simply provide solutions for selected energy issues; instead, they form a fundamental element in creating intelligent, self-sustaining, and sustainable energy networks for the future [5].

1.3 Key Insights

- ✓ Energy Management Optimization: AI and metaheuristic algorithms have been particularly useful in establishing prognosis and near real-time control models in EMS for guaranteeing reliability and optimization in systems of renewable energies [6].
- ✓ Load Forecasting: Modern artificial neural networks and combined optimization models present impressive predictive capabilities for identifying energy consumption and generation trends.
- ✓ Renewable Integration: To properly integrate RESs, the fluctuating features of the renewable sources have to be considered and solved, in which metaheuristics provide the necessary, scalable algorithm [7].
- ✓ Smart Home Energy Management: Metaheuristic optimization-based demand response models claim a massive role in curtailing energy demands, costs, and emissions in residential environments [8].
- ✓ Future Directions: More research and development on optimization algorithms and their implementations in the twenty-first-century complex and ever-changing energy systems are vital to circumventing existing challenges and attaining worldwide energy sustainability objectives [9].

As a reference, this paper brings the audience, including researchers and practitioners, up to speed with the current trends in optimization techniques and the future direction of Smart Grid.

2. Literature Review

The challenges that come with the need for innovative energy systems have precipitated the use of electrical smart grids (SGs) that offer advanced potential for power management. Using artificial intelligence, optimization algorithms, and monitoring, SGs increase energy systems' robustness, dependability, and cost-effectiveness. These systems are developed to solve important issues including, but not limited to, voltage instability, reactive loads, power outages and incorporation of renewable energy technologies. Due to their applicable range from the household to the industrial field, SGs have become an important research area for efficient energy use. This literature review explores contemporary developments in SGs within the last five years, emphasizing optimization algorithms employed towards improving energy management while lowering operating expenditure.

As detailed in the paper [10], the book presents a comprehensive collection of select proceedings from the International Conference on Smart Grid Energy Systems and Control (SGESC 2023), focusing on the decarbonization and digitization of energy systems. The volume addresses key topics, including smart grid and microgrid control, optimal energy scheduling, distributed generation, and wind energy applications for remote electrification. Additionally, it explores forecasting methodologies for loads and daily energy demand, reactive power management, Volt-Var control, and ancillary services. The role of FACTS devices, feasibility studies of PV/Wind hybrid systems, electricity markets, power system stability, energy storage systems, and electric vehicles are also highlighted, providing valuable insights for academic researchers and industry practitioners.

In the research presented in [11], achieving sustainable development goals necessitates integrating renewable energy systems (RESs) into existing energy infrastructures, which involves addressing complex decision-making processes. The study provides a detailed evaluation of metaheuristic algorithms and multi-criteria decision-making methodologies, supported by bibliometric analysis and academic literature review. Highlighting key trends and developments, it underscores the potential of metaheuristics to enhance sustainable development by optimizing resource allocation, reducing environmental impacts, and increasing societal benefits. These approaches address sustainability's economic, social, and environmental pillars while improving the administration of RESs.

As outlined in [12], the adoption of innovative green technologies for energy production has been driven by technological advancements, urbanization, high-energy demand, and global efforts to reduce carbon footprints. Integrating these technologies with traditional grids offers significant benefits but introduces challenges such as power mismatches caused by intermittent renewable energy production and nonlinear consumption patterns. An efficient Energy Management System (EMS) is vital for addressing uncertainties in renewable energy production and load demand while optimizing distributed energy generation. The study highlights artificial intelligence-based solutions, including advanced metaheuristic algorithms for optimal scheduling, long short-term memory and convolutional neural networks for accurate forecasting, and multi-agent systems for decentralized control. These approaches enhance EMS performance and mitigate the stochastic nature of renewable energy systems, supporting improved reliability and efficiency.

The analysis in [13] identifies the load margin as a critical index for assessing how much a power system's load can be increased without compromising stability. To address the growing operational uncertainties in modern power systems, an optimization model was proposed for configuring a Physics-Informed Neural Network (PINN) to predict load margins. The model also determines the optimal placement of Phasor Measurement Units (PMUs) at system buses, with their measurements serving as inputs for the PINN. The study enhances the network's generalization capabilities by integrating physical knowledge of the power system during the PINN training phase. Using the IEEE 68-bus and Brazilian interconnected power systems as test cases, three metaheuristics—the Hiking Optimization Algorithm, Artificial Protozoa Optimizer, and Particle Swarm Optimization—were applied. The results demonstrate the advantages of incorporating physical insights into PINN training and optimizing PMU locations for accurate load margin predictions.

As outlined in [14], a machine learning-based framework was developed for accurate short-term load forecasting in residential buildings, aimed at assisting energy companies in balancing energy consumption and generation. The framework involves two innovative components: the analysis of relevant features such as time, calendar, and weather using a correlation matrix, followed by applying an optimized eXtreme Gradient Boosting model to select key features, reducing model complexity. An intelligent parallel structure integrating gated recurrent units and convolutional neural networks is proposed for load forecasting across different resolutions with minimal errors. Particle swarm optimization is utilized to tune the hyperparameters of the proposed model, ensuring optimal configuration. Evaluation using the real-time Mashhad dataset demonstrated superior performance compared to recent models, achieving a root mean square error of 44.28, mean absolute error of 29.32, and mean absolute percentage error of 3.11%. These advancements enhance decision-making and operational efficiency for power companies and smart grids.

As discussed in [15], the reprint compiles 15 articles addressing optimization and control techniques within energy management systems (EMS), emphasizing mathematical modeling and simulation. The topics covered include demand-side management, artificial intelligence optimization for renewable energy systems, and frequency regulation via virtual power plants, and EMS in smart grids, mini-grids, and microgrids. Additional focus areas include energy conservation strategies, control theory, load and renewable energy generation prediction methods, and energy management solutions for smart cities and homes. The publication highlights recent advancements in EMS mathematical modeling and simulation, offering insights crucial for the strategic planning and optimal operation of hybrid energy systems, whether in grid-connected or islanded configurations. This comprehensive resource provides significant value for researchers and practitioners in EMS, renewable energy systems, and power system optimization.

The analysis conducted in [16] evaluates the reliability of power systems incorporating wind farms using the Jellyfish Search Algorithm (JFSA) and distribution generation. The study emphasizes the challenges of assessing reliability due to the random behavior of wind generation, which complicates predictions. Reliability indices such as Loss of Load Expectation (LOLE) and Loss of Load Probability (LOLP) are calculated to evaluate system performance under variable wind power conditions. The study uses Minitab statistical software to derive equations for LOLP and LOLE based on wind power variations. The proposed methodology is applied to the RBTS 6-bus and IEEE 24-bus RTS systems, providing a framework for generation expansion planning incorporating renewable energy sources.

As outlined in [17], the integration of Electric Vehicles (EVs) into Smart Grids (SGs) is explored, focusing on their role as adaptable Energy Storage Systems (ESSs) and their contribution to ancillary service markets. The study highlights the challenges of intermittent renewable energy sources and PV technology in EV

charging, necessitating an efficient Energy Management System (EMS). To address these challenges, an Improved Honey Badger Algorithm (IHBA) is proposed for optimizing charging and discharging profiles at the Point of Common Coupling (PCC) by integrating EV parking lots, solar panels, and dynamic loads. Using dynamic programming and PV generation forecasts, the IHBA lowers grid reliance while enhancing SG efficiency. The results, tested in MATLAB, demonstrate superior performance compared to the Whale Optimization Algorithm (WOA) and Elephant Herding Optimization (EHO), with improved total harmonic distortion voltage (3.12%), reduced power loss (0.197 kW) and higher efficiency (98.47%).

As detailed in [18], this study presents a smart home load scheduling system to enhance energy conservation and environmental sustainability. A demand response (DR) model incorporating an energy consumption scheduler (ECS) is proposed to optimize the operation of smart appliances under real-time price-based demand response (RTPDR). The ECS leverages multiple optimization algorithms, including particle swarm optimization (PSO), genetic optimization algorithm (GOA), wind-driven optimization (WDO), and a hybrid genetic wind-driven optimization (HGWDO) algorithm, to schedule appliance operations effectively. Batteries stabilize generation fluctuations to address the intermittent and time-varying nature of renewable energy integration into smart grids (SGs). Compared to existing models, the simulation results demonstrate the system's capability to minimize utility bills, pollutant emissions, and the peak-to-average demand ratio (PADR). This approach provides a practical solution for improving smart home energy management, promoting sustainability, and mitigating environmental impact.

In the research presented in [19], an efficient bi-level energy management strategy (EMS) is proposed to optimize the operation cost of a grid-connected microgrid, addressing operational constraints and uncertainties in renewable energy sources and load demand. The first level of the strategy involves optimal day-ahead scheduling in two stages: determining the optimal operating points of energy sources for the upcoming day and managing controllable loads. The second level of the EMS involves real-time rescheduling and adjusting the set points of energy sources based on actual solar irradiance, wind speed, load, and grid tariff. A novel real-time strategy is introduced to ensure economical operation under uncertainties. To address the complex, constrained, nonlinear optimization problem of day-ahead scheduling of batteries, the Honey Badger Algorithm (HBA), a recent meta-heuristic algorithm, is employed. The results demonstrate that the HBA-based bi-level EMS provides optimal real-time economic operation for a grid-connected microgrid despite uncertainties in weather, utility tariffs, and load forecasts.

In the study referenced in [20], a strategy is developed for scheduling Energy in a community microgrid, considering electricity costs, loads, and climate uncertainties. These microgrids, self-sufficient localized energy networks capable of generating, storing, and supplying Energy, can operate independently or in coordination with a country's utility grid. The proposed system integrates a utility grid, a solar photovoltaic (PV) plant, a wind generation system, a micro-turbine, an energy storage system (ESS), and a load. A flexible mathematical model is formulated and solved using the marine predator algorithm (MPA), an efficient meta-optimization method. The strategy uses intelligent management software to efficiently meet load demands while minimizing costs by maximizing resource utilization.

In the research presented in [21], the grey wolf optimizer (GWO) algorithm is employed to optimize a microgrid system for effectively dispatching power to loads economically. The microgrid system components are modeled and analyzed using the MATLAB/Simulink platform. The primary objective of the proposed GWO approach is to minimize the overall operation cost of the microgrid. A detailed investigation is conducted on power dispatch optimization and cost minimization for both island and grid-connected modes of the microgrid, considering the impact of running costs. The results demonstrate that the GWO optimizes the overall system cost and ensures efficient load sharing within the microgrid.

In the study referenced as [22], microgrids are explored as a promising solution for reliable, sustainable, green energy sources, particularly for households and the growing demand for electric vehicle (EV) charging. This research proposes using a deep Long Short-Term Memory (LSTM) with a Deep Brief Network model to predict the grouped energy load and solar energy output in a community microgrid. A hybrid metaheuristic algorithm is employed to optimize the load dispatch of grid-connected community microgrids incorporating solar elements and energy storage systems. The study evaluates three scheduling scenarios to determine the most efficient dispatch design of such systems. The proposed model ensures a supply-demand equilibrium by integrating prediction outcomes to account for solar Energy and residential load uncertainties. The

objective is to develop an energy-efficient system that can effectively balance the load and power of the microgrid while remaining stable despite the fluctuations in energy generation and consumption.

As highlighted in the study described in [23], electrical Microgrids (MG) are seen as the primary solution for the transition of power systems. Renewable energy sources and energy storage systems are unavoidable components of the microgrid that ensure sustainable and reliable operation. EMS work is at the core of these systems, where several tasks involve monitoring, forecasting, controlling, and scheduling the power source and storage unit. EMSs also consider significant technical limitations, including the cost of operations, degradation of storage and emissions. In order to address the problem of microgrid optimization, a framework that combines data forecasting, optimization and control, called Energy Management and Control Systems (EMCS), has been proposed. Additionally, AI and ML are beginning to be used to enhance EMS efficiency and optimize the framework of microgrids regarding the integration of renewables and power-sharing strategies.

In the research presented in [24], electrical smart grids (SGs) are highlighted as critical systems for improving electricity distribution from power plants to consumers by reducing costs and power failures and enhancing energy management. SGs offer significant advantages, including bi-directional communication, enhanced stability, power failure detection, and connectivity with appliances for real-time monitoring. To improve performance, these systems advantage advanced technologies such as modeling, monitoring, optimization, and Artificial Intelligence (AI). The paper explores recent developments in SGs, mainly focusing on optimization techniques like Genetic Algorithm, Particle Swarm Optimization (PSO), and Grey Wolf Optimization, which have been applied to maximize energy management and minimize costs. A systematic review of 145 research works published between 2011 and 2022 revealed that PSO is the most commonly used optimization algorithm in SG research. The study also examines objective functions, Energy, cost optimization parameters, and identifies ongoing research challenges.

The literature review on metaheuristic algorithms and their use in energy management systems in smart grids is presented in detail in Table 1 below. Some areas identified for further emphasis include optimization methods applied to energy timetables, demand estimation, and the incorporation of renewable forms of power. It indicates methods such as Particle Swarm Optimization (PSO), Grey Wolf Optimization (GWO), and other hybrid deep learning methods, which have influenced dealing with dynamic energy systems' difficulties. However, the table also reveals some limitations, including scalability problems, computational costs, and the variability of renewable sources of Energy, which call for further studies to improve the flexibility and effectiveness of such algorithms within enormous applications.

Table 1: Summary of Literature Review

Study Reference	Research Focus	Key Findings	Methodologies Used	Limitations
[10]	Decarbonization and digitization of energy systems	Emphasizes renewable integration, energy scheduling, and distributed generation	Optimization and AI-based techniques	Implementation challenges and scalability
[11]	Renewable energy systems (RES) integration	Enhances sustainability via metaheuristics and decision-making	Bibliometric analysis, optimization techniques	Complex decision-making

[12]	AI for smart grid optimization	Improves EMS performance with AI and metaheuristics	Neural networks, multi-agent systems	Stochastic renewable energy challenges
[13]	Load margin assessment in power systems	Optimizes PMU placement using PINN	Hiking Optimization Algorithm, Particle Swarm Optimization	Training complexity
[14]	Short-term load forecasting	Enhances accuracy via feature selection and deep learning	eXtreme Gradient Boosting, GRU, CNN	Limited dataset generalization
[15]	Energy management systems (EMS)	Focuses on hybrid energy systems and control	Mathematical modeling, simulations	Cost and degradation issues
[16]	Reliability in wind-integrated systems	Proposes JFSA for reliability analysis	Statistical modeling	Wind generation variability
[17]	Electric vehicle integration in smart grids	Optimizes V2G and G2V profiles using IHBA	Dynamic programming, metaheuristics	Renewable intermittency challenges
[18]	Smart home energy scheduling	Demonstrates demand response efficacy with optimization	PSO, GOA, WDO	Renewable energy fluctuation
[19]	Bi-level EMS for microgrids	Introduces real-time scheduling	Honey Badger Algorithm	Renewable and load uncertainties
[20]	Community microgrid energy scheduling	Optimizes operations under uncertainties	Marine Predator Algorithm	Climate data variability
[21]	Cost optimization in microgrids	Minimizes costs using GWO	MATLAB/Simulink	Operational cost focus
[22]	Load balancing in microgrids	Balances load with LSTM and optimization	Hybrid metaheuristics	Solar and load uncertainties
[23]	Microgrid EMS frameworks	Combines forecasting and optimization	Data-driven control systems	Integration of renewables

[24]	Smart optimization grid	Highlights PSO as dominant optimization tool	Systematic review	Scalability and real-time applicability
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Altogether, the optimization algorithms, including PSO, GA, and GWO, are valuable for enhancing brilliant grid performance. Thus, these techniques help control Energy and its cost-effectiveness to improve the efficiency of Energy and its control in further moving toward intelligent energy solutions and sustainability. The review of recent literature stresses the gradual enhancement of the usage of SG all over the world and in various markets. Thus, the main drawbacks and open issues are observed in the application, and widespread solutions are associated with scaling these technologies and handling dynamic grid behaviors. The further development of these optimization models should be the main direction of future research, as well as the discovery of new algorithms and the mitigation of the mentioned shortcomings in the literature to enhance SG performance and sustainability.

3. Discussion

Using metaheuristic algorithms to control smart grids has revealed considerable enhancements in energy systems, diminishing some of the complications experienced in conventional power systems. These challenges include integrating renewable energy sources, Real-time load forecasting and efficient energy management. It is important to note that integrating artificial intelligence and metaheuristic techniques has improved Smart Grids in managing dynamic energy demand and supply conditions that are both reliable and cost-efficient.

3.1 He is interested in the topics associated with optimization algorithms and energy systems.

Hence, the prominence of optimization algorithms like Particle Swarm Optimization (PSO), Genetic Algorithm (GA) and Grey Wolf Optimization (GWO) has been instrumental in improving the efficient operation of energy systems. Such algorithms are highly suitable for solving nonlinear problems typical for Energy- ethics, such as demand forecasting or renewable energy schedules. For example, PSO has been observed to be highly effective in cases where real-time optimization is needed because the approach is simple and faster than other algorithms, making it more suitable for use in energy systems. Likewise, GA and GWO were important in analyzing distributed systems regarding capacity and lower operating expenses [25], [26].

3.2 Renewable Energy Resources Integrated

Solar and wind power are stochastic energy resources: This implies that they are not constant in terms of supply, which has problems in the standard grid system. Using metaheuristic algorithms, Smart Grids resolve these issues by considering different aspects of energy storage, generation scheduling, and load distribution. Research has shown that these policies help ensure demand-side response to supply and renewable energy inputs that can be volatile. This approach has also led to the utilization of RHesses and renewable resources, which has also led to considerable scale reduction in the emission of greenhouse gases and use of fossil fuels [27], [28].

3.3 Energy Management Systems

This paper reveals that integrating advanced methodologies has boosted EMS in smart grids. They now contain real-time control and optimization functionality, metrics-based predictive tools and autonomous control mechanisms that enhance the value of these systems. The HBA and MPA have previously been used to improve the control of hybrid microgrids economically and effectively [29], [30].

3.4 Challenges and Future Directions

However, some limitations and drawbacks prevent the effective use of metaheuristic algorithms in Smart Grids. The applicability of these algorithms for large-scale energy systems, the factor of real-time computation and the incorporation of new and developing renewable energy technologies are the directions

for future research. Furthermore, the prespecialisation of new metaheuristic algorithms used in Smart Grids could provide even higher efficiency and sustainability [31], [32].

The application of metaheuristic algorithms on Smart Grids can be described as revolutionary, providing new practical solutions to important problems concerning the energy sector. Due to their capacity to operate in highly nonlinear energy systems, they are now some of the most valuable tools in developing green and sustainable Energy. Future work must address these limitations and improve the scalability and computational burden of distributed state estimation for PHEVs in large-scale power systems.

4. Conclusion

Metaheuristic algorithms enable a smart grid in the contemporary energy management system. The algorithms considered serve vital objectives of the energy strategy as they concern the operational issues of distribution and incorporation of renewable power and other aspects of energy systems' improvement in general effectiveness and ecological friendliness. Smart Grids have made the required change and strengthened the energy sector solutions to significant problems of voltage unstableness, reactive power management, and operational costs due to modern computational techniques. This paper focuses on metaheuristic algorithms, including Particle Swarm Optimization (PSO), Genetic Algorithms (GA), and Grey Wolf Optimization (GWO), in redesigning energy structures to support world sustainable development objectives.

Extremely valuable to this study is identifying the potential and variety of metaheuristic algorithms in handling the challenges inherent in energy systems. Metaheuristic methods are formulated and operated for nonlinear and stochastic characteristic patterns, making them optimal for fluctuating and varying energy requirements. Perfect insight has been employed in the peer-to-peer matching of electric resources and load forecasting in real time to make the grid more substantial and reliable. Furthermore, by incorporating these algorithms with other forms of machine learning, including Long Short-Term Memory (LSTM) networks, the algorithms have become more competent and adaptive to result in efficient energy systems.

The same review also reveals the significance of incorporating renewable electricity into Smart Grids. Metaheuristic algorithms are incredibly beneficial for mitigating the intermittency of renewables, managing energy storage, and meeting supply-demand metrics. These developments help achieve lower emissions, which in turn help promote cleaner power alternatives essential for switching to sustainable energy systems. Moreover, the effectiveness of using these algorithms is illustrated by their application in EMS, which leads to improvements in the planning and operation of microgrids, smart houses, and hybrid energy systems with economic and environmental advantages.

However, the research also points out several directions, which could be investigated in future studies. The issues involve the capability of metaheuristic algorithms for enormous-scale applications in a grid platform, the performance ability of real-time framework, and the requirement for improved algorithms to adapt to proliferating energy problems. Future research should concentrate on creating new heuristics to suit the further advanced characteristics of smart grids and implementing more integrated schemes that use the advantages of different algorithms. Solving these challenges offers opportunities for metaheuristic algorithms to transform energy systems toward optimization, sustainability, and stability. Therefore, this paper implies that metaheuristic algorithms are important as dexterous techniques for present energy concerns and in defining the emerging brilliant green adaptive energy facilities.

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