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ECONOMIC AND ENERGY MANAGEMENT OF MICROGRID USING METAHEURISTIC TECHNIQUES: A REVIEW

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Abstract

To address problems with energy management in microgrids, this paper examines several methods for calculating emissions and economics. Microgrid efficiency may be improved by integrating various energy sources, such as solar, wind, and battery energy storage systems (BESS). This can be achieved by a thorough examination of various technologies and existing innovations in the field. Keeping the system stable, controlling energy, ensuring a steady power supply, reducing emissions of greenhouse gases, and keeping operational costs down are the main goals. This paper presents a variety of optimization algorithms for energy management systems, including hybrid, opposition-based, metaheuristic, AI, and classical approaches. Microgrid design and development in the modern day is thoroughly examined in this book, which covers topics such as artificial neural networks (ANNs), fuzzy logic, ML, neural networks, reinforcement learning, etc. The essay acknowledged more than 200 scholarly journals.

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Keywords: Microgrid, Metaheuristic techniques, Artificial Intelligence, Economic & Emission Dispatch, Grid Modelling, Optimisation.

1.Introduction

Designed for small towns, villages, and business areas, a microgrid (MG) is a kind of localized electricity system. Microgrids comprise distributed generators, solar energy systems, and wind energy systems among other micro sources. Among the advantages are dependability, utilization of renewable energy, financial savings, environmental protection, higher efficiency, and a consistent supply of electricity. Ideal adopting meta-heuristic techniques, the Economic Load Dispatch and Combined Economic Emission Dispatch (CEED) of the microgrid is not working as expected from the Energy Management System (EMS). The CEED advises industrial units to be set within specified limits in order to avoid pollution and fuel expenses.

The primary energy sources are nuclear, fossil fuels (coal, oil, and natural gas), and green energy (sun, wind, wave, tidal, hydropower, geothermal, biomass, and hydrogen). Fuels are the primary source of sulphur dioxide (SO2), which is produced during the burning of coal, oil, and gasoline. Due to its affordability and accessibility, coal provides a significant portion of India's energy. However, burning coal releases a lot of toxic substances, including particulate

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matter, sulphur dioxide, carbon dioxide, nitrogen dioxide, and volatile organic compounds. Carbon dioxide and sulphur dioxide combine to form acid rain, and volatile organic compounds (VOCs) weaken the ozone layer and exacerbate smog. However, using renewable energy sources to generate power does not harm the environment.

Furthermore, the MG is commonly found at the user end and is a component of a low-voltage network. MG may function in two modes: off-grid (not linked to the grid) and on-grid. A point of common connection (PCC) connects the microgrid (MG) to the electrical grid while it is in "on-grid" mode. The off-grid mode allows the MG to run independently because it is not connected to the power grid. Because it is difficult to operate the microgrid in islanded mode, it is necessary to implement a management strategy that is composed of many tiers in order to maintain a low voltage and frequency inside the microgrid and to enhance the power quality.

In order to guarantee that there is always power, a reliable connection between the microgrid and the main grid is required. Electric grids and alternative microgrids are two examples of potential sources of electricity that come from the outside. In the event that the nation's domestic energy output is insufficient, electric power is imported from other countries. When both the amount and demand of external energy sources are regulated, a price-based demand response (DR) system functions more effectively when it is implemented. In Figure 1, we see examples of many sorts of renewable energy sources, such as solar cells and wind turbines. All of these are referred to as renewable distributed generators, or RDGs for short. Through the use of renewable distributed generation (RDG), microgrids are able to reduce their reliance on polluting fuels. The intermittent nature of renewable energy sources has caused these RDGs' availability to be unstable. Concurrently, the provisions from RDGs frequently do not correspond with the burden requirements. As a result, the microgrid employs batteries to store renewable energy that is not promptly consumed. The magnitude of renewable distributed generators and batteries in practical microgrids often fails to meet the needs of users. Additionally, the behaviour of users can result in erratic and inconsistent demands. When the capacity of internal resources is insufficient to meet peak demand, an external energy supply is required.

These microgrids are classified into two categories: AC and DC. Coal is the primary energy source for the AC grid, while DC microgrids rely on renewable energy sources. DC loads are increasingly being employed due to their numerous benefits, including increased efficiency, reliability, the absence of skin effect, reduced electricity bills, reduced copper losses, high stability, low installation costs, reduced carbon emissions, and ultimately reduced pollution as a result of the absence of coal in the primary fuel form.

A great deal of study has been conducted on the control mechanisms of hybrid AC-DC grids, and this research has been carried out in a variety of different strategies. The two most significant challenges that microgrids face are stability and voltage control.

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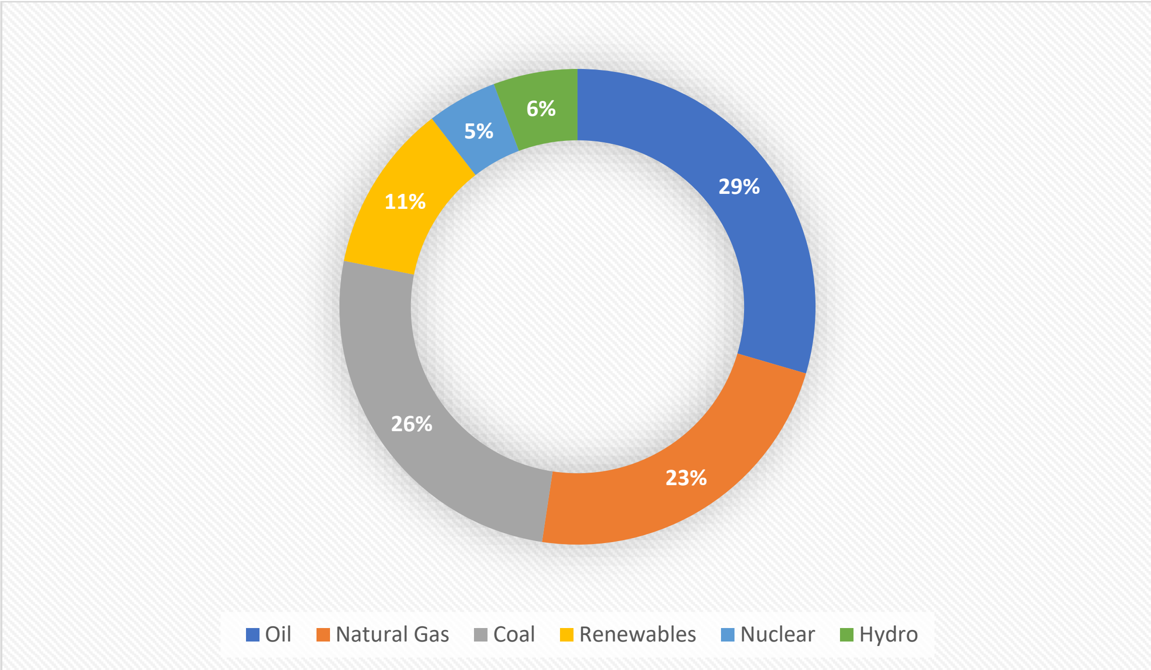

Figure 1. Total energy consumption of the World by various sources in 2024

1.1 Overview of microgrid

The non-convex, intricate, and non-linear constraints of microgrids necessitate the use of heuristic and metaheuristic methods to improve system performance, as a result of their time-varying topologies. Heuristic and metaheuristic optimisation incorporates a variety of algorithmic classes, such as those with dynamic and static objective functions, iterative, single-point, population-based, and nature-inspired objective functions.

Population-based, nature-inspired optimisation methods employ the principles of natural evolution that are inherent in biological systems to organise the search process, out of these categories. Notwithstanding the heightened computational complexity resulting from the expanded population size of solutions, these algorithms remain autonomous, simple, reliable, efficient, and conducive to extension and hybridization. As a result, population-based metaheuristics, known as p-metaheuristics, are preferred for their ability to concurrently explore the search space, hence decreasing convergence and execution times.

1.2 Overview of Metaheuristics techniques

In the past decade, a plethora of meta-heuristic optimisation algorithms have been developed and implemented to resolve a variety of optimisation challenges in a variety of domains. Researchers continue to suggest novel and enhanced optimisation methodologies that have the potential to enhance the outcomes of a variety of optimisation challenges. These methodologies are designed to facilitate greater exploration and exploitation capabilities. Approximation approaches known as meta-heuristics do not ensure global optimality. However, because of their ability to successfully address the limitations, these strategies are widely used. Several simulation experiments are conducted to validate the efficacy of a conclusion, as these

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techniques are approximation methods. Researchers have developed an interest in hybrid optimisation methodologies. The amalgamation of many optimization techniques yields hybrid optimization methodologies. These solutions are superior and more robust than traditional optimization methods in achieving a global optimum outcome. Consequently, numerous hybrid optimization techniques have been formulated and documented in diverse scholarly articles in recent years.(Imchen & Das, 2023) [82]

In this paper the microgrids are divided into three main sections. First, is the structural analysis of microgrids which comprises of the various sources of energy used for example solar, wind, hydro, biomass as well as hybrid systems. Second, is the economic and emission analysis of microgrids which comprises of the various cost reduction techniques being used in microgrids along with those used to minimize greenhouse gas emissions caused by the microgrids. Third, is the role of artificial intelligence in identifying the various challenges and research gaps and also improving the overall efficiency for the system.

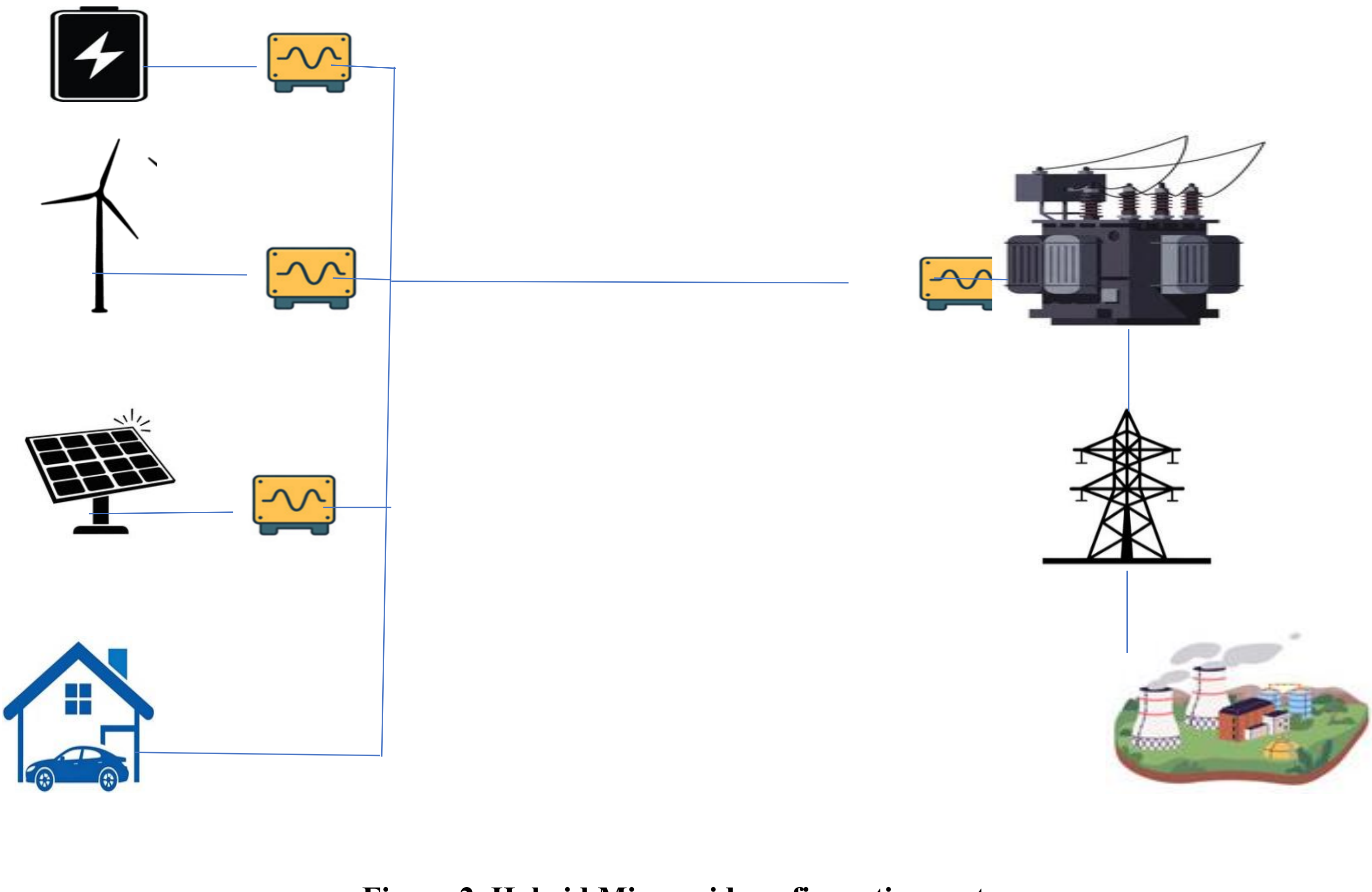

Figure 2. Hybrid Microgrid configuration system

2.Structural Analysis of Microgrids

A fractional order (FO) control approach is utilized, and the parameters of the FO proportional integral derivative (PID) controller are optimized using a global optimization algorithm to satisfy system performance criteria. A kriging-based surrogate modelling technique is employed for the costly evaluation of goal functions in optimization-based controller tuning.

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Numerical simulations are used to validate the suggested approaches. The advantages and disadvantages of kriging-based surrogate modelling are analysed, and the results of both the FO and integer order controllers are compared to conventional evolutionary optimisation methods.(Pan & Das, 2015) [4]

Finding the best way to run an energy storage system is the aim of this research. This approach should be able to balance the costs of running the microgrid with the system's useable life while also accounting for practical limitations and varying energy needs. The goal of optimization is to lower the system's overall cost function while meeting customer demand and ensuring the security of the electrical network. A microgrid that includes an office complex, an industrial facility, a hydroelectric power plant, a photovoltaic power plant, and battery storage is the subject of a case study. The results of the simulation show that the proposed approach is feasible and effective in satisfying the load requirements and reducing total costs. (De Leone et al., 2017) [9]

This study addresses the Combined Economic Emission Dispatch (CEED) problem, which involves scheduling producing units within their constraints to minimize fuel costs and emissions, hence obtaining optimal system expenses. The Interior Search Algorithm (ISA) is utilized to address the Economic Load Dispatch (ELD) and CEED problems. By removing solar energy from all sources, removing wind energy from all sources, and removing both solar and wind energy from all sources, four different scenarios are used to reduce total costs and emissions. The results in two cases, CEED with emissions and ELD without, demonstrate the ISA's comparison to the Cuckoo Search Algorithm, Ant Colony Optimization, and Reduced Gradient Method (RGM). The results are calculated over a 24-hour period for different power needs. The outcomes of ISA, which show a higher level of cost reduction than those of RGM, ACO, and CSA, verify the algorithm's efficacy.(Trivedi et al., 2018) [10]

This paper presents a solution to the economic dispatch (ED) issue for a microgrid (MG) using four optimization methods: particle swarm optimization (PSO), lambda logic, direct search method (DSM), and lambda iteration). Distributed generators (DGs) that may be controlled remotely should reduce fuel consumption in the microgrid. The need for both grid-connected and isolated services is one operational restriction of microgrids. Another is that demand could fluctuate, and non-dispatchable distributed generators have an output limit. To find out how these constraints affect fuel costs, two test systems' dispatchable distributed generators are monitored daily. A simulated microgrid with three control zones is utilized in the early testing. Renewable energy sources, such as solar and wind power, and distributed generators that are not dispatchable, situated inside each control zone, are inputs to the model microgrid system. A microgrid with 33 nodes and 2 control zones is utilized in the second trial. This includes distributed generators, loads that may and cannot be dispatched, and so on. (Maulik & Das, 2017) [12]

This study examines innovative methods for utilizing hybrid energy sources. The text outlines the physical modeling of renewable energy resources utilizing various approaches and optimization principles for hybrid networks. This work has offered a global survey on the current state of optimization approaches, particularly those pertaining to isolated microgrids in the existing literature. The prevailing trend in optimizing hybrid renewable sources indicates that artificial intelligence offers significant enhancements for microgrid operations without the necessity for considerable long-term meteorological data. (Dawoud et al., 2018) [13]

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The approach for improving energy management systems (EMS) in DC microgrids spanning several objectives is described in the study. It is based on hybrid energy storage systems (HESS). The optimization seeks to lower the risk of power supply failure (LPSP) and operating and maintenance costs. The DC microgrid ensures that all distributed generators (DGs) retain the proper power flow characteristics throughout operation. The total degree of satisfaction of Pareto solutions for power flow optimization may be ascertained by employing a multi-objective non-dominated sorting method, an improved differential evolution (DE) technique, and the maximum membership degree principle (MMDP) of fuzzy control. The results of the simulation show that the suggested EMS optimization approach successfully strikes a compromise between cost effectiveness and microgrid operating dependability. (P. Wang et al., 2018) [14]

This research uses data from the Advanced Metering Infrastructure (AMI) to show a new way to control energy and run AC/DC microgrids that are isolated in almost real time. The study shows a complex multi-objective program that works well in a range of situations by using AMI-based methods for energy optimization and saving. The study says that using new ideas, like the Operation Value Factor (OVF), can help systems work at their best while also cutting their costs by a large amount. The results show that correct load models could make AC/DC microgrids work better. A modified 33-node islanded AC/DC microgrid case study is used to test the suggested system's practicality and efficiency. The system includes different AC/DC generation units and loads. (Manbachi & Ordonez, 2019) [15]

A memory-based genetic algorithm (MGA) for effectively allocating power-generating tasks among several distributed energy resources (DERs) is presented in this study. MGA is used by the smart grid system to reduce the cost of energy production. It effectively makes use of the energy produced by solar photovoltaic systems, wind turbines, microgrids, and combined heat and power systems. Using MGA, we compare the results of two different types of particle swarm optimization (PSO) to the genetic algorithm (GA). The simulation results show the advantages of the proposed MGA approach. (Askarzadeh, 2018) [16]

This article talks about a way to make the most of the potential of advanced hybrid energy storage systems (HESS), solar, wind, and other energy sources all at the same time. This method builds a microgrid that is linked to the main power grid using both battery energy storage (BES) and supercapacitor (SC) technologies. One goal is to lower prices, improve reliability, and cut down on greenhouse gas (GHG) emissions. By using a segmented approach, the difficult optimization problem can be solved in a new way, while at the same time working time and complexity are reduced. An original search method was used to find out the sizes of solar photovoltaic (PV) systems and wind turbines (WT). These measurements are very important for figuring out what size hybrid energy storage system (HESS) should be. A study of greenhouse gas pollution, dependability, and cost shows that the suggested method is possible. To figure out the size of a grid-connected microgrid, the method uses battery energy storage systems, solar energy storage systems, and wind energy storage systems. It is looked at how much microgrids that use mixed energy storage systems, standard production methods, and battery energy storage cost, how reliable they are, and how much pollution they produce. A microgrid that uses mixed energy storage technology has been shown to be more reliable and cost-effective, as well as reducing greenhouse gas emissions. (Akram et al., 2017) [17]

Six meta-heuristic algorithms have been reviewed and categorized into three groups: Differential Evolution, Particle Swarm Optimization, Firefly Algorithm, Whale Optimization, Genetic Algorithm and Teaching-Learning Based Optimization. Evolutionary Algorithms, Swarm Intelligence and Education. A comparison analysis utilizing diverse performance indicators for standard benchmark tasks is performed, incorporating a challenge for reducing operational costs in a smart micro-grid (SMG). A proposed Smart Microgrid (SMG) aims to incorporate utility-connected energy resources, including wind, solar, fuel cells, diesel generators, micro-turbines, battery storage and electric vehicle technology. This work will aid scholars and engineers in choosing an appropriate optimization technique for tackling limited micro-grid optimization issues. A thorough examination of techniques to reduce operational costs in micro-grids has been performed, based on an extensive survey and implementation. (Khan & Singh, 2017) [18]

A model predictive regulator, which regulates power flow in tie-lines and frequency fluctuations inside the microgrid, balances the system's total active power output and consumption. Two microgrids with wind farms, conventional thermal and hydroelectric generators, photovoltaic (PV) systems, energy storage systems, and active power demand make up the system being studied. Predictive control is used to regulate power exchange between two microgrids. (Tungadio et al., 2018) [28]

Weighted Information Gap Decision Theory (W-IGDT), an improved variant of IGDT that produces time-dependent, risk-based robustness bands instead of static ones, is presented in this paper. To integrate power flow constraints and producing unit operating conditions into the optimization process, a proposed Energy Management System (EMS) uses a W-IGDT design. The W-IGDT-based EMS can be utilized to achieve peak performance while lessening the intermittent character of renewable energy sources, as demonstrated by a CIGRE microgrid benchmark. (Nasr et al., 2020) [30]

A two-phase iterative approach is described in this document. The optimal sizing problem is first resolved using a customized evolutionary algorithm meta-heuristic technique. Next, a nonlinear solution is deployed to address the operational problem based on the derived design and investment options. This approach, which makes use of a thorough power flow algorithm, yields exact solutions and thereby resolves issues related to microgrid operation. The ability to take potential outcomes into consideration guarantees that the suggested size solutions are appropriate for both regular operations and temporary circumstances. Model convergence is made achievable with very low processing effort because to the genetic algorithm. A generalizable microgrid with AC and DC generators and loads, as well as a variety of storage devices to provide benefits, is used to implement the suggested model. (Rousis et al., 2020) [31]

This article demonstrates the value of a hybrid microgrid system that integrates gas power, photovoltaics, batteries, and wind energy using a computer model. The ideal dimensions of the suggested system are meant to lower energy prices (COE) while increasing reliability and efficiency, as evidenced by the probability of power supply loss (LPSP). An effective microgrid was developed using sophisticated optimization techniques, including the hybrid particle swarm-gravitational search algorithm (PSOGSA), the Water Cycle Algorithm (WCA), the Whale Optimization Algorithm (WOA), and the Moth-Flame Optimizer (MFO). The optimization techniques used have been carefully assessed. One calculated the ideal system

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component size using real-time weather data from the Egyptian hamlet of Abu-Monqar. To ascertain if the optimization technique was successful in locating the best option, a statistical analysis was conducted. It was evident from the simulations that the hybrid WOA performed better than the other methods. (Zaki Diab et al., 2019) [36]

EMS for the optimal functioning of a MG is presented. Photovoltaic arrays (PVs), wind turbine generators (WTs), energy storage systems (ESS), micro-turbine units (MT), and fuel cell units (FC) are integrated. We use probability modeling and scenario selection techniques to handle the irregular and uncertain data from renewable energy sources and network demand. The proposed EMS calculates the ESS's charging/discharging power, active/reactive power (P-Q) contributions from neighboring distributed resources, and more. The system does this by analyzing the amounts of active and reactive electricity that are exchanged with the main grid, as well as daily data estimates for various hourly situations. All technological limitations have been met while optimizing the secondary grid's profitability. Through the use of creative improvements in the study, the BAT algorithm is optimized. To solve the microgrid's energy management optimization challenge, an improved BAT approach with a thorough rule basis is used. A comparison of its performance with the existing literature is used to illustrate its proficiency. (Elgamal et al., 2020) [47]

In order to enable applications running on a Fog Micro Data Center (fogMDC), a data center driven by Software Defined Networking (SDN), to use cleaner energy while cutting costs, the study aims to identify the most effective renewable producing choices for microgrids. This study makes use of real meteorological data from Tamil Nadu. This document outlines the first tasks suggested for two different scenarios—economic modeling and performance modeling—to enable MG-powered fogMDCs. The objective of the proposed economic modelling study is to ascertain the most effective specifications for distributed energy resources, associated financial costs, and the integration of renewable energy within a microgrid-operated fogMDC. Ensured Quality of Service (QoS) in time-sensitive IoT applications is facilitated by SDN, which enhances the efficient utilisation of distributed Virtual Machine (VM) resources. (Padma Priya & Rekha, 2021) [50]

This investigation establishes an optimal energy dispatch strategy for microgrids that are either grid-connected or standalone. Fuel cells (FC), microturbines (MT), BESS, diesel generators (DG) and photovoltaic (PV) systems are all incorporated into the strategy. An innovative multi-objective solution for microgrid energy management (MGEM) is proposed, which is expressed as mixed integer linear programming. A demand response program is added to this system to show how it affects the best energy dispatch and the techno-commercial benefits. To optimize energy storage system (ESS) scheduling, an approximation interface has been developed. Power grid power exchange, charging and discharging schedules, energy costs, initial costs, fuel costs, penalties for greenhouse gas emissions, and photovoltaic systems, wind turbines, diesel generators, microturbines, fuel cells, converters, and batteries to store energy are all shown in the simulations. The results indicate that an independent hybrid microgrid system reduces CO_2 emissions by 51.60% in comparison to a conventional grid-only system. The implementation of numerous evolutionary algorithms provides additional evidence of the efficacy of this reduction. (Murty & Kumar, 2020) [51]

This study suggests a generation cost model that accounts for no-load costs, power losses in the microgrid (MG), non-linearity of DG losses, and start/stop costs for distributed generation

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(DG). The optimization issue becomes significantly more challenging to solve when it is converted to a non-convex mixed integer nonlinear (MINL) problem. A global optimization solution is provided by the BARON methodology's Branch and Reduce optimization Navigator technique. Reducing expenses and emissions is the goal of a single-objective problem. The goal of a multi-objective problem is to operate within the allowed cost and emission constraints. The constraints approach establishes appropriate bounds for multi-objective circumstances by using the results of single-objective scenarios. The capacity of an ESS to mitigate power outages and lower emissions is also taken into account. The DC microgrid, which includes fuel cells (FC), microturbines (MT), diesel engines (DE), and battery energy storage systems (BES), is the subject of the research. The research looks at how Egypt's infrastructure requirements change throughout the course of the year. (Mosa & Ali, 2021) [53]

Hybrid microgrids that employ distributed generation and renewable energy sources are the focus of this research, which seeks to optimize the utilization of integrated resource planning in such systems. The tiny amount of inertia in microgrids and the unpredictable nature of green energy may be mitigated with the correct combination of demand-response support (DRS) and virtual-inertia support (VIS) solutions. The first plan is to set up three independent microgrids that would draw power from the local biofuel, wind, and solar resources. Demand response units, which resemble electric vehicle charging stations, and storage-based virtual inverter systems allow microgrids to manage both supply and demand. The proposed system's source and load changes may be modeled in MATLAB. The system is designed over a 12-month period using real-time data on solar and wind power. Quite aggressive and chaotic An innovative method for improving power and frequency management in distributed microgrids, selfish-herd optimization (QCSHO) involves calibrating controllers. One approach would be to compare the system's results with those of more recent and innovative approaches. Without modifying the controller settings, we examine how the proposed microgrids manage frequency, voltage, and tie-line load variations in five distinct severe scenarios involving changes to both sources and loads. A total of 22 distinct microgrid-compatible DRS and VIS unit distributions were found to conform to the final results. When you compare the responses of all the integrated tools together, it becomes simpler to see how to use them best. (Barik & Das, 2021) [55]

In this study, a new approach that blends stochastic and stable optimization approaches for scheduling renewable-based multi-carrier microgrids (MCMGs) is presented. The MCMG is able to fully engage in the gas, electricity, and district heating industries. By maximizing the usage of the MCMG's main components—the boiler unit, electrical energy storage (EES), thermal energy storage (TES), power-to-gas (P2G) storage, and wind turbine—we want to lower the overall energy consumption and CO2 emissions of the facility. This is how we have to satisfy our energy needs. In order to assist the MCMG in the energy market become more cost-effective, we look into the significance of demand response (DR) programs, namely the day-ahead load shifting program, and electric vehicle parking lots (EV-PLs). Through the reduction of unpredictability in wind output, electricity consumption, the energy market, and electric vehicle (EV) operating patterns, including battery longevity, arrival and departure times, and other features, this approach precisely mimics the MCMG. GAMS software was used to solve this MILP model. You can assess the efficacy of the suggested system by using a significant number of case studies. Through the use of demand response programs, multi-carrier energy storage, and plug-in hybrid electric cars, the MCMG may lower its overall energy usage by 2.36% and emissions costs by 3.51%. (Ding et al., 2021) [58]

For a rural community in South Australia, PSO, DE, WCA, and GWO are used to maximize the capabilities of four different AC-coupled freestanding microgrids, which include diesel generators, fuel reservoirs, solar photovoltaics, wind turbines, and battery energy storage. Electricity's net present value over a twenty-year period is the objective function. In the optimization study, empirical data on the site's yearly capacity consumption, ambient temperature, solar insolation, and wind speed are used. In the Australian market, the economic analysis takes into account the costs of capital, replacement, and maintenance for components. The operational power reserve is maintained by employing the principles of static and dynamic reserves. An uncertainty analysis is conducted by utilising a decade of actual data on renewable energy and load consumption. A sensitivity analysis is conducted to evaluate fluctuations in battery pricing and capacity. In order to assess the efficacy of the algorithms that have been implemented, a comparison is made of the computational duration, economic and operational outcomes, and optimisation convergence. The findings indicate that the differential evolution technique is inadequate to resolve the optimal scale issue of the freestanding microgrids that were examined. (Fathi et al., 2022) [59]

In this research, we examine several methods of load distribution and how to construct and enhance off-grid mixed microgrid systems. A number of cost evaluations, user reactions, and proposed system components make up this evaluation. This research expands two common components of hybrid microgrids in Bangladesh. A wind turbine, storage, solar photovoltaic system, and diesel engine make up this system, which has a load profile of 27.31 kW. The predictive dispatch, load following, generator ordering, cycle charging, and combination dispatch methods of HOMER are enhanced by it. Researchers are now looking at microgrids that have the lowest carbon dioxide emissions, net present value, and levelized energy costs. The two microgrids are examined using the HOMER program following the testing of the five alert systems. It is thus possible to predict the future performance of the microgrids' power system using MATLAB Simulink. The findings provide a method for estimating the potential costs and component needs for achieving optimal performance in various load sharing situations using the proposed microgrids. The optimal approach to implementing microgrids is "Load Following," as it minimizes CO_2 emissions, operational costs, levelized energy costs, and net present cost. Its steady power system reaction is further demonstrated by the modeling findings. In the proposed off-grid hybrid microgrid system, the combined dispatch technique results in the greatest levelized cost of energy, net present cost, operational cost, and CO_2 emissions. (Ishraque et al., 2021) [68]

A multi-microgrid employs a hierarchical Demand Response (DR) technique to optimize Frequency Regulation (FR) services. A wind turbine-powered engine and a biogas and fuel facility are now being tested at the first location. Vegetation used to produce biomass, biogas, and solar photovoltaics is located in the second testing zone. Our recommendation is to use a fuzzy (PI)-(PD) controller, depending on the microgrid model under consideration. Quasi-opposition based Harris Hawks Optimization (QOHHO) is used to find the ideal values for the given constraints. Increased load frequency control (LFC) efficiency is demonstrated by utilizing natural transmission delay in the demand response cycle within a mixed hierarchical demand response architecture. Using the physical constraints of the system, we investigate the demand responsiveness and stability of the multi-microgrid with stochastic delays. It is also possible to establish a consistent criterion for assessing the test system's accuracy. The

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outcomes show that the suggested approach performs better than many control measures. (Saxena et al., 2022) [71]

This study shows how to use virtual inertia control (VIC) technology to control frequency through a sample microgrid system that is networked. Test Area 1 has a biodiesel plant, a biogas plant, and a wind power engine. All of the sites' biogas, biofuel, solar photovoltaic, and VIC systems are built into Test Area 2. A changed type-I fuzzy controller is needed to handle the microgrid model that is being looked at. The Quasi-Opposition-Based Harris Hawks Optimization (QOHHO) method was used to find the best way to calibrate the different controller gains. The better dynamic performance of the system shows that the suggested VIC method can work. (Kumar et al., 2022) [72]

The goal of this work is to predict how well microgrids will work when they are linked to the grid and find the best stochastic scheduling approach. The microgrid's combined energy storage device will be made up of a battery and a supercapacitor. This method is applied as a stochastic mixed-integer linear programming (MILP) problem to a modified ORNL-DECC microgrid test system. Unexpected factors include system load requirements, solar generation, and wind energy. These are demonstrated using Gaussian distributed models with standard deviations of 10%, 5%, and 3%, respectively. The unpredictable nature of the schedule is investigated by adjusting the power output of the supercapacitor from 0 kW to 20 kW. The timing data is analyzed using both random and deterministic optimization techniques. Random success is calculated using the estimated total cost as well as the expected value of perfect information (EVPI). The data help to balance the benefits and drawbacks of employing supercapacitors for microgrid timing. (Budiman et al., 2022) [74]

In this paper, an algorithm is introduced that is intended to optimize electricity and operational costs. The algorithm determines the optimal size of Battery Energy Storage Systems (BESS) to maximize power delivery within a specified time frame, based on C-rate. This is achieved by achieving energy management for a microgrid system that consists of PV-BESS and diesel generators. The C-rate of the BESS is employed to designate discharge intervals of 0.5 and 1, which correspond to discharge durations of 2 hours and 1 hour, respectively, in relation to the maximum load demand. This is done in order to determine the savings on the power account for these discharge durations. The objectives are achieved through the use of Nonlinear Model Predictive Control with the FMINCON solver, which is compared to heuristic-based techniques for an array of Battery Energy Storage System sizes and durations. In order to optimize the size of BESS, the prediction horizon is divided into two discrete time frames based on the charging and discharging durations within a 24-hour period. The efficient reduction of electricity expenditures through optimal scheduling of battery energy storage system charge and discharge intervals is demonstrated by simulation outcomes derived from Nonlinear Model Predictive Control utilizing FMINCON. (Vaka & Matam, 2022) [78]

The idea of a self-sufficient microgrid that runs on solar, wind, and waste from both residential and agricultural sources is best shown by this story. The possibility of accuracy is increased by the theory's capacity to gather biowasserstoff. Maintaining a dependable power supply in response to fluctuating demand is challenging due to the varied characteristics of these resources across different locations. In order to minimize apparent output fluctuations in the system, MATLAB simulates the microgrid using a unique Green Leaf-hopper Flame optimization (GLFO) technique and an objective function based on the Integral-Square of

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Weighted Absolute Error (ISWAE). Merit scores, which assess the system's performance effectiveness, are computed using four controllers, five algorithms, and five objective functions. According to PID controller calibration analysis, this study shows that the suggested GLFO operates better within the parameters of ISWAE. This study looks at the computational effects of five adverse situations, like as shifts in the supply and demand for the microgrid. The system's adaptability is demonstrated by its ability to use recorded data in real time. (Sahoo et al., 2022) [79]

HOMER conducted a thorough investigation into many optimization techniques before revealing the fastest solution. With an LCOE of $0.64/kWh, one of the least expensive solutions also had the lowest NPC ($387,185). To meet capacity requirements, the hybrid energy system is designed to make use of power-generating modules that are suitably scaled and specified. These modules include wind turbines, solar cells, electric motors, and gas engines. It is related to the Net Present Cost (NPC) and Levelized Cost of Energy (LCOE) of the optimization issue. Many approaches of optimization are tested and implemented. Moreover applied is a sophisticated control system for frequency and voltage regulation. This spans proportional-integral-derivative (PID) control and fuzzy logic controllers (FLC) with automated tuning. MATLAB: Simulink runs the islanded hybrid microgrid system totally and implements the control strategy. Based on simulation results, the suggested FLC can maintain the voltage and frequency within the permissible range under a range of running conditions. We examine attentively the operating exclusively on solar and wind energy hybrid microgrid management and optimization. (Shezan et al., 2023) [85]

The configuration, control, difficulties, and reach of DC microgrid systems are all thoroughly examined in this research. A range of common designs, new developments in control techniques, operational difficulties, and DC microgrid commissioning are all covered. Along with the energy-saving research, there is a case study that shows how DC systems are better than AC systems. (Maurya et al., 2023) [92]

This research offers a thorough method and a new MPPT technique for better energy management. To provide the best control strategies while handling errors and disruptions, we use robust model predictive control (RMPC). Standard model predictive control (MPC) techniques are outperformed by RMPC. To boost output, the solar system employs limited tuna swarm optimization (MTSO), a complex maximum power point tracking optimization technique. In terms of maximum power point (MPP) tracking under various irradiation conditions, MTSO performs better than drone squadron optimization (DSO) and slime mold optimization (SMO). The results of the test show that both the RMPC method and the MTSO technique can be used to get the most energy out of solar power, keep batteries in good shape, and use them. Real-time modeling is used on the OPAL-RT device to test a control method. (Buchibabu & Somlal, 2024) [94]

This paper offers a thorough scientific approach for constructing ideal hybrid microgrid systems (HMGs). Several hybrid microgrid designs comprising several producing sources are proposed to satisfy the electrical needs of tiny communities in Malaysia. Keeping operating limits in mind, the Grey Wolf Optimizer (GWO) helps to lower energy expenses (COE) in dollars per kilowatt-hour ($/kWh). The reliability and efficiency of the hybrid system may be evaluated using four metrics: the electric power supply likelihood (LPSP), the storage

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performance index (ISP), the renewable energy index (IRE), and the additional energy index (IEE). Load following (LFs) and cyclic charging (CCs) two energy management techniques direct these types. The optimal design revealed a 75.3% of total energy output from renewable sources, a fraction of unserved loads of 0.039, and an energy expenditure of $0.24/kWh. The findings imply that the distribution of producing resources is much influenced by the temperature. The results are assessed with a genetic algorithm (GA). (Wahab et al., 2023) [95]

S No.	Author	Year	Objective	Inspiration
1	Indranil Pan, et al.(Pan & Das, 2015)[4]	2014	It is shown how fractional order (FO) controllers may be used in a microgrid.	In addition to MG control, this approach may be used for other computationally costly power system optimization challenges.
2	R. De Leone, et al. (De Leone et al., 2017)[9]	2016	A mathematical method for the administration of energy in a microgrid.	This approach satisfies the load and reduces total costs.
3	Indrajit N. Trivedi, et al.(Trivedi et al., 2018)[10]	2016	To solve CEED problem using Interior Search Algorithm (ISA), therefore reducing the system cost.	Effectiveness of the suggested algorithm is demonstrated by the cost savings that ISA shows when compared to RGM, ACO, and CSA.
4	Avirup Maulik, et al. (Maulik & Das, 2017)[12]	2017	To lower the microgrid's dispatchable DGs' fuel costs.	Two types of tests are used to see how all the restrictions affect how much fuel dispatchable distributed units use every day.
5	Samir M. Dawouda, et al.(Dawoud et al., 2018)[13]	2017	It examines the most recent energy practices in hybrid sources and presents physical modeling of the RER using a variety of methodologies and optimization principles for hybrid networks.	With a focus on isolated microgrids specifically, a worldwide overview of the status of optimization strategies in the literature is offered.
6	Panbao Wang, et al. (P. Wang et al., 2018)[14]	2017	Outlines a method for optimizing EMS in a DC microgrid by utilizing Hybrid Energy Storage Systems (HESS) from a variety of perspectives.	This proposed optimization establishes an efficient balance between the economic viability and dependability of the microgrid.

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7	Moein Manbachi, et al.(Manbachi & Ordonez, 2019)[15]	2017	The use of Advanced Metering Infrastructure (AMI) data to islanded AC/DC microgrids in order to provide adaptive and near real-time energy management.	The application of precise load models enhances the efficiency of AC/DC microgrids.
8	Alireza Askarzadeh (Askarzadeh, 2018)[16]	2017	It suggests a memory-based genetic algorithm (MGA) for dividing up power production among different distributed energy resources (DERs) in the best way.	The outcomes confirm MGA's superiority over two PSO variations and GA.
9	Umer Akram, et al. (Akram et al., 2017)[17]	2017	Presents an approach for combined capacity optimisation of RES in a grid connected MG.	This method is more cost-effective and produces fewer greenhouse gas emissions than alternative solutions.
10	Baseem Khan, et al. (Khan & Singh, 2017)[18]	2017	A review of six meta-heuristic algorithms selected from three different categories is done to select a suitable optimization technique.	Chooses a suitable optimization technique to address micro-grid optimization issues with restrictions.
11	D. H. Tungadio, et al.(Tungadio et al., 2018)[28]	2018	A model predictive regulator controls power flow in tie-lines and microgrid frequency oscillations to balance total active power output and demand.	The power transfer between two microgrids is regulated using a predictive control technique.
12	Mohamad-Amin Nasr, et al. (Nasr et al., 2020)[30]	2019	The proposed W-IGDT is intended to reduce the system risk associated with renewable energy injections at each discrete time interval within a short-term operational framework.	The method is effective in maximizing performance and mitigating the variability of renewable energy sources.
13	Anastasios Oulis	2019	A two-stage iterative method is given to	This method employs a comprehensive power flow algorithm to capture voltage and

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	Rousis, et al. (Rousis et al., 2020)[31]		formulate a suitable combined optimization solution for addressing the optimal sizing issue of hybrid AC/DC microgrids.	frequency, deliver precise answers, and tackle the operational issues of microgrids.
14	Ahmed A. Zaki Diab, et al.(Zaki Diab et al., 2019) [36]	2019	To ensure high power supply dependability while meeting the planned location's load demand at the lowest possible cost.	WOA's great operational efficiency, as demonstrated by the energy cost and convergence rate, makes it the most effective approach among those suggested for tackling the optimization problem.
15	Mohamed Elgamal, et al.(Elgamal et al., 2020) [47]	2020	EMS optimizes microgrid performance by improving secondary grid profitability while respecting technology constraints.	On comparing with other approaches this EMS is faster, cost effective and hence has better performance in microgrid.
16	Padma Priya R, et al. (Padma Priya & Rekha, 2021)[50]	2020	Finding the most effective renewable energy production ability would lower the costs of investments and increase the use of renewable energy in microgrids.	The microgrid is operated by fogMDC, which is further enhanced by SDN to optimize the use of distributed Virtual Machine (VM) resources, thereby ensuring Quality of Service (QoS) in time-sensitive IoT applications.
17	V. V. S. N. Murty et al. (Murty & Kumar, 2020)[51]	2020	For microgrids that are independent or linked to the grid, an optimal energy dispatch technique is suggested.	When compared to a conventional grid-only system, the comparison findings validate the superiority of this technology and the reduction of CO2 emissions in a freestanding hybrid microgrid system.
18	Magdi A. Mosa, et al. (Mosa & Ali, 2021)[53]	2020	The suggested EMS accounts for the DG's starting and shutdown expenses in addition to the distribution system's nonlinear losses and no-load costs.	Multi-objective operation scenarios, least cost scenarios, and minimum emission scenarios are used to illustrate the precision and resilience of the global optimization solver BARON.
19	Amar Kumar Barik, et al. (Barik &	2021	Examining the efficacy of integrated resource planning in distributed, mixed-source microgrids	An assessment of their total replies is used to describe the best way to distribute integrated resources across 22 different DRS and VIS unit allocations across different microgrids.

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	Das, 2021)[55]		that generate electricity from renewable sources.	
20	Xiaonan Ding, Qun Guo, et al. (Ding et al., 2021)[58]	2021	To cut MCMG's energy costs and CO2 emissions.	GAMS solves this MILP model. The case study shows how demand response, multi-carrier energy storage, and EV-PLs may reduce energy and pollution costs.
21	Mohammad Fathi, et al. (Fathi et al., 2022)[59]	2021	This study compares four metaheuristic methods for remote hybrid microgrid sizing.	The best technology in terms of cost-effectiveness is the DG-PV-WT-BB system. On the other hand, there are cases where the DE technique falls short of optimizing the performance of isolated microgrids.
22	Md. Fatin Ishraque, et al.(Ishraque et al., 2021)[68]	2021	An islanded hybrid microgrid is designed to optimize resource planning and operation at two distinct locations, utilizing a variety of dispatch strategies.	Optimizing the microgrid design while accounting for the real distribution network data and the stochastic behavior of solar and wind resources can improve the analysis.
23	Abhishek Saxena, et al.(Saxena et al., 2022) [71]	2022	In order to enhance Frequency Regulation (FR) in a multi microgrid, a hierarchical Demand Response (DR) strategy is suggested.	The proposed algorithm's superior performance in comparison to alternative control techniques is corroborated by the results.
24	Sameer Kumar, et al. (Kumar et al., 2022)[72]	2022	The use of virtual inertia control (VIC) is suggested for frequency management in a linked test microgrid system.	The performance is enhanced, which indicate higher efficacy of VIC.
25	Firmansyah Nur Budiman, et al.(Budiman et al., 2022)[74]	2022	It tests a microgrid with a grid-connected HESS and the most efficient stochastic scheduling.	Variable energy costs will strengthen the microgrid-grid relationship.
26	Srinivas Sandeep Kumar Reddy Vaka,	2022	For microgrids, a proposed algorithm seeks to maximize the goals of	By coordinating their charge and discharge cycles, Battery Energy Storage Systems (BESS) effectively lower power costs.

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	et al.(Vaka & Matam, 2022)[78]		power and operating expenses.	
27	Subash Chandra Sahoo, et al. (Sahoo et al., 2022)[79]	2022	Proposes an algorithm that minimizes the apparent power deviations of an isolated MG.	We can see that the algorithm is superior since we employ five of them, together with five objective functions and four controllers.
28	Sk. A. Shezan, et al.(Shezan et al., 2023)[85]	2023	Optimization approaches are compared by settlement speed and current cost.	This technology makes it possible to build and run mixed microgrids that are powered by both solar and wind power in remote places.
29	Salwan Tajjour, et al.(Tajjour & Chandel, 2023)[91]	2023	An advanced energy management system is proposed that uses the Grey Wolf Optimizer to control demand and an artificial neural network to anticipate electricity generation.	In clear, sunny conditions, the losses of conventional solar microgrids are reduced by 100%, while they are reduced by 42.6% in overcast conditions.
30	Rinki Maurya, et al.(Maurya et al., 2023)[92]	2023	A thorough examination of the configuration, control, scope, and challenges associated with DC microgrid systems is provided.	The article presents an energy-saving analysis and the advantages of DC systems in comparison to AC systems.
31	Prathikantham Buchibabu, et al. (Buchibabu & Somlal, 2024)[94]	2023	A new MPPT technique and an integrated strategy for improved energy management are proposed.	The simulation results demonstrate its efficacy in attaining optimal energy, battery management, and optimum solar power extraction.
32	Ahmed Sahib Tukkee, et al.(Wahab et al., 2023)[95]	2023	Provides a thorough methodology for optimizing hybrid microgrid designs.	Assists in selecting the type and dimensions of the suitable hybrid MG system based on climatic conditions.

3.Economic & Emission Dispatch Analysis of Microgrids

An approach known as model predictive control is utilized in this article in order to maximize the operations of a microgrid while simultaneously accommodating time-varying demands and operational restrictions. The issue is presented in the context of mixed-integer linear programming (MILP), and it is feasible that commercial solutions may be capable of effectively addressing it. This is accomplished without the need for complex heuristics or decomposition methods. There is a significant improvement in both the computation efficiency and the quality of solutions when using the MILP formulation. A MG case study is carried out to determine the efficiency of the online optimization-based control approach. In addition, a microgrid that is now under experimental testing and is located in Athens, Greece, uses a technology that is equivalent. The findings of the experiment indicate that this method is not only feasible but also effective. (Parisio et al., 2014)[1]

Reactive power from distributed generators (DGs) is efficiently distributed by this approach to lower the cost function, which is the total of all quadratic voltage variations at the DG nodes and other crucial system nodes. This approach entails the optimization of the individual objective function of each distributed generator (DG) while taking into account locally acquired information from neighboring nodes within the microgrid. Furthermore, the optimization process involves the essential nodes that are devoid of DGs. The subgradient method's integration enhances its applicability, even in the absence of microgrid data, and the microgrid is able to maintain a consistent voltage profile as a result of this control and optimization strategy. The investigation of microgrid active power loss reveals that the unified voltage profile inherently facilitates. (Maknouninejad & Qu, 2014)[2]

This study presents a two-tier hierarchical optimization approach for the energy management systems of distinct microgrid communities within the framework of a smart grid. The execution is implemented incrementally, commencing at the lowest tier and progressively escalating to minimize operational expenses. The charge and discharge power of the energy storage system, the power output of the microgrid generators, and the electricity exchanged with the upstream grid are all controlled at a reduced level to guarantee optimal operation. The outputs inform the lower level of the higher level's limitations. The higher level, independent of internal microgrid components, is tasked with assessing the power of microgrid community level devices (MCLD) and the electricity sent through distribution networks. This conclusion is derived from the outcomes of the subordinate level. To eliminate nonlinearity, the model employs the linearization approximation, and implicit logical constraints are included to address the issue of nonconvexity. We analyze a case study of an authentic system deployed in Guangxi Province, situated in South China. The findings indicate the extent of the strategy's success. Two of the four evaluated scenarios have been determined to be cost-effective, and it is advised that they be implemented for MGC operation. (Tian et al., 2016)[5]

The aim of this study is to present Particle Swarm Optimization (PSO), a global optimization technique, and to illustrate its possible applicability to the current problem. The outcomes of the exhaustive search have been utilized as a benchmark for the purpose of assessing and validating the optimization process. According to the findings, the PSO approach is an efficient strategy that can be utilized to determine an optimal design solution for a microgrid while incurring a relatively minimal amount of effort in terms of computing. Due to the

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implementation of this PSO-based technique on a significantly smaller computer platform, the total amount of time required for the calculation of the case study was reduced by a factor of six. (Ghaem Sigarchian et al., 2016)[11]

This strategy tries to provide outside assistance by connecting an overloaded or renewable-generating MG to one or more suitable adjacent islanded MGs at the lowest possible cost. To support overloaded or overgenerating MGs, certified nearby MGs must have adequate loading capacity or unused generation capacity. The technique determines the best balance of energy storage charging and discharging, renewable curtailment, and demand response as additional choices. Its base is a modified version of particle swarm optimization with high convergence that can be used in real time. It is set up an objective function that takes into account many operational, technical, and environmental problems, and the major limitations are made clear. Its functionality is proven by a set of virtual tasks. (Arefi & Shahnia, 2018)[19]

This paper applies the Pareto Concavity Elimination Transformation (PaCcET) to the security-constrained multi-objective optimal dispatch (SC-MOOD) problem. The PaCcET adjusts each point individually before moving it from a multipurpose region to a specific target location. It finds every non-dominated region in the original multi-objective space by applying a single-objective optimizer to a linear set of updated objectives. Simulations of a microgrid with several distributed energy resources (DERs) operating in both grid-connected and islanded configurations show that the proposed paradigm is effective. The results are then compared to two existing benchmarks: the non-dominated sorting genetic algorithm II and multi-objective particle swarm optimization (MOPSO). (Sarfi & Livani, 2018)[20]

The method thinks about the costs of running the system when demand changes and green energy output changes, as well as problems of sustainability and changing supply sufficiency. This way quickly handles any event that is different from the MG's power or frequency. In order to find the best network setup for the MG, the optimal producing levels of the deployable sources are changed. The goal is to lower the use of green energy sources while increasing internal support. This will be done by changing loads and the charge or discharge capacity of present battery storage systems. This short-term operating method uses metaheuristic optimization to look at the prices and states of microgrid components at the central controller and figure out the best thing to do. A program called MATLAB is used to make sure that the suggested way works. (Shoeb et al., 2018)[21]

A professional consumer microgrid equipped with several storage units, renewable energy generation capabilities, and load transfer capacity may be suitable for this architecture. A comprehensive bi-level energy sharing model is established to provide prosumers and storage facilities with a consistent energy sharing schedule, therefore alleviating the effects of market price fluctuations and uncertainties associated with renewable energy. Suitable linearization techniques enable the efficient resolution of the bi-level optimization issue as a unified MILP problem. In the second stage, an online optimization model is established, enabling any prosumer to continually adjust their hourly energy plan based on the most current system conditions. This method originates from the proposed penalty system for prosumers who alter their prior energy share agreements. The benefits of this energy-sharing technique are illustrated in the simulated situations. (Cui et al., 2019)[22]

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In order to establish a rapid optimal control issue, numerous robust optimization methodologies are suggested. Mixed integer linear programming can swiftly ascertain the global optimum of a terse control issue. The control schedule is routinely revised by the rolling horizon controller of the EMS in order to resolve the control problem. The piecewise linearization method, which utilizes nonlinear efficiency maps, precisely determines the state of charge of ESS. External operational conditions, such as demand response and peak control, can be dynamically implemented during the optimization process. The proposed method guarantees effective management in the areas of cost reduction, accurate regulation, and external impact. (Choi et al., 2019)[24]

The mixed-integer nonlinear programming (MINLP) framework is the most suitable elucidation for the actual planning challenge of the project. This example illustrates the problems of uneven power at the point of common coupling (PCC), voltage irregularities, and disparities in synchronous generator (SG) efficiency. This issue may be transformed into a functional mixed-integer linear programming (MILP) system by the application of linearization techniques. A choice in operational planning executed by two-stage robust optimization (TSRO) may endure variations in voltage-dependent load factors, prevailing market prices, and erratic renewable energy production. The resolution will be achieved by the implementation of columns and constraints (C&CG). The resilient system undergoes evaluation utilizing IEEE 37-bus and IEEE 60-bus inputs. (Sepehry et al., 2019)[32]

This study is mostly about how to use an energy control system in microgrids that run on batteries. It is possible for the EMS to work both separately and with the grid. The suggested EMS is modeled as an optimal power flow (OPF) problem using the e-constraint approach. Finding the current references that the EMS uses to manage MG sources is the task at hand. In order to keep active power losses below predetermined limitations and reduce the overall cost of generating, the optimization problem uses a battery management technique based on power gradient limiting. The performance of the suggested EMS in two scenarios is assessed, enabling a thorough analysis and validation of the system. The first considers a dispatchable source and a non-dispatchable source, whereas the second considers both a dispatchable source and a storage device. Furthermore, the test results showed that the proposed EMS is efficient in both working modes and can maintain the storage device's state of charge (SoC). (Agnoletto et al., 2019)[33]

This work utilizes MILP to address the economic scheduling problem. Employing a commercial solution, such as E-solver, may expedite the resolution of the problem. The transmission loss problem may be handled using the interior point technique, namely the L-solver, even if it is built with nonlinear programming (NLP). The E-solver provides the L-solver with an economic priority power scheduling plan, which is then used to solve the precise power flow scheduling plan for the whole microgrid. The suggested decomposition approach for the planning model aims to solve it in a time-sharing way. Cost-effective, efficient, and rapid real-time control is achieved by combining the properties of the two optimizers with a compelling matching method. The effectiveness of the online optimization-based control technique is assessed using a DC microgrid case study. When compared to the standard interior point technique, simulations of an eight-node DC microgrid show that it saves operating expenses by 12:10% while increasing computation performance by 80:18%. The recommended optimization strategy reduces latency, which speeds up the real-time control and optimization process. (Su et al., 2021)[43]

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The goal of the CFLCP is to find the best way to set up, put, and spread renewable distributed generators (DGs) in a utility-based microgrid after a major grid failure, even if the microgrid is still separate from the main grid. Some of the problems that the proposed SS-CFLCP aims to fix are the high costs of initial investments, running and maintaining the network, the distance that electricity has to travel, the chance that too many renewable energy sources will cause problems with reverse power flow that could hurt the main grid, and the number of power outages caused by major grid disturbances. There are also talks about building placement and reaching people in the area. The model's applicability and utility are significantly enhanced by the inclusion of a financial constraint for the installation of distributed generators. The success of the proposed strategy is demonstrated through a case study that utilizes distributed generators that are based on solar and photovoltaic technologies. (Kizito et al., 2020)[48]

A home microgrid with interconnected smart users is advised to adopt a day-ahead energy scheduling system. Each customer possesses noncontrollable loads (NCLs), renewable energy systems (RESs), energy and comfort-based controllable loads (CLs), and plug-in electric vehicles (PEVs). Scheduling is intended to fulfill contractual, comfort, and device specifications while concurrently minimizing projected energy usage. Consumers unaware of their energy needs may find it challenging to transmit generated renewable energy to the grid. The topic was initially formulated as a min-max robust problem to ascertain the most effective charging and discharging schedules for Energy Storage Systems (ESS) and Plug-in Electric Vehicles (PEVs). Consequently, the issue is reformulated as a mixed-integer quadratic programming problem through the use of duality theory in multi-objective optimization. This update rectifies the significant counterpart of the scheduling problem. How can the conservativeness, peak-to-average ratio, rate of constraint violation, and cost savings of the proposed methodology be evaluated across different situations, considering the uncertainty budget? A case study is conducted to assess the efficacy of the technique within a comparable complete framework. (Hosseini et al., 2021)[49]

This paper implements cross-layer optimum energy scheduling (CLOES) in a multi-microgrid system. Numerous elements of a smart city community are included in this mechanism, including single-family, multi-dwelling, commercial/office, and industrial units. Each of these types of units is unique in its distributed loads and generators. Cross-layer sequential coordinated operations are implemented by the top and lower levels. There are several microgrids in the lower layer, while the distribution system operator is in the higher stratum. A multi-microgrid system's dependability depends on the top and lower layers' interlayer sequential interactions, which guarantee each microgrid's ideal energy scheduling. The results of the simulation show that CLOES substantially cuts costs in a multi-microgrid system when compared to separate microgrids that trade with the power grid. (Funde et al., 2020)[52]

Utilizing energy storage effectively, a unique lightning search algorithm (LSA) approach is developed to guarantee excellent power supply at a low cost. This strategy is supported by the day-ahead optimal scheduling controller. An adept MG manager will facilitate the decrease of operating expenses for distributed energy resources (DER) by supervising the charging and discharging operations of energy storage systems. A 14-bus test system using real load fluctuation data gathered over a 24-hour period in Perlis, Malaysia, serves as an example of the effectiveness of the upgraded controller. The findings indicate that the energy storage-based microgrid's upgraded controller lowered power usage, resulting in a 62.5% reduction in energy

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costs. It demonstrates the controller's performance by outperforming particle swarm optimization approaches and the backtracking search algorithm in terms of time consumption (2915.2 minutes) and iterations (53.56). Therefore, by ensuring the best possible functioning of distributed energy resources, the optimized controller may increase the efficiency of energy storage in microgrid energy management. (Roslan et al., 2021)[56]

A hybrid version of the Grey Wolf Optimizer Algorithm Crow uses positional update principles from the Crow Search Algorithm and techniques from the population-based Sine Cosine Algorithm to calculate sine and cosine. This is called the Crow Search Algorithm with Sine Cosine Algorithm Collaboration (GWOSCACSA). The suggested method cuts the cost of the generator for the microgrid system by a huge amount. The findings show that using the Time of Usage (TOU) market pricing method cuts generation costs compared to a passive grid case. This means that the system spends 47% less on generation because the dynamic grid isn't used as much. A scientific study of GWOSCACSA reveals that it works better than other algorithms that have been written about. (Dey et al., 2022)[69]

The optimal scheduling of microgrids has been achieved by developing an energy management method that is based on Mimosa pudica. This method is designed to mitigate production overheads while maintaining system limits. This approach is intended to regulate the distribution of power among distributed resources and utilities by means of a standardized communication protocol. The mimosa plants enhance the accuracy of solutions by preserving diversity in solutions and leveraging historical information through memory, thereby facilitating the adaptation to dynamic contexts. Microgrid topologies are clearly given precedence over isolated, grid-tied, and resynchronized scenarios in this technique. Comparing the novel methodology to previous methods, the numerical results show an 8% improvement in profit, suggesting that it has a higher capacity for optimization and a faster rate of convergence. (V et al., 2022)[70]

This study suggests two approaches for figuring out the optimal scale of an autonomous microgrid and energy management: a rule-based method and a metaheuristic optimization search technique (MOST). The microgrid's components are powered by the energy management system (EMS). As a result, MOST increases the effectiveness of emergency medical care. The effectiveness of six distinct MOSTs is compared in this study. The goal of the reconstruction is to faithfully depict Maiduguri, Nigeria's temperature. The grasshopper strategy outperforms all other multi-objective optimization techniques studied, according to the data. It performs 3.0, 5.8, and 3.6% better than the particle swarm, ant lion, and grey wolf optimizers, respectively. An affordable and sustainable energy source has emerged as a result of the widespread usage of EMS for microgrid management. This design reduces CO2 emissions by 92.3% and fuel consumption by 92.4% when compared to a petroleum engine that runs on fossil fuels. (Bukar et al., 2022)[76]

It critically evaluates and explores a variety of energy management optimization strategies, focusing on economic dispatch, demand management, forecasting, and unit commitment. Because of their effectiveness and simplicity, mixed integer programming techniques are frequently utilized to handle energy management concerns in microgrids. Because of the decentralized nature of the EMS problem in microgrids, multi-agent techniques and metaheuristic algorithms outperform traditional solutions in terms of system efficiency. Only demand management and forecasting can take use of advanced optimization techniques. As previously stated, a community microgrid requires both a sophisticated energy management system and transactive energy sharing. (G. S. Thirunavukkarasu et al., 2022)[80]

A novel Kho-Kho optimization (O-KKO) approach based on opposition learning is presented for scheduling distributed generating units in an isolated microgrid. The strategies' effectiveness is assessed using 23 benchmark functions. This strategy is used to improve the scheduling of production units in order to decrease hazardous gas emissions and costs. The efficacy and superiority of this approach are evaluated by comparing it to a variety of current algorithms. When compared to KKO, using O-KKO in the Dynamic Economic Emission Dispatch (DEED) issue saves $1 when Renewable Energy Sources (RES) are missing and $21.2 when RES are present. When dealing with dynamic economic load dispatch (DELD) problems, O-KKO saves $2.9 without renewable energy sources (RES) and $4 with RES. (Imchen & Das, 2023)[82]

This study is mostly about heat exchanges, power and heat units (CHP), shunt capacitors, renewable energy sources, and a microgrid that is linked to the power grid (GMG). GMG systems are also put next to zero bus concept-based microgrid (ZBMG) systems. The eight original microgrid designs use a variety of sustainable and non-renewable energy sources. The GMG and ZBMG methods are used to group them into these eight groups. The fuzzy method and particle swarm optimization (PSO) technologies work together to achieve many goals at the same time. These include reducing energy loss and pollution and lowering overall costs. The point estimate method (PEM) is used to reduce error even more in green energy sources. It is looked into how each microgrid design, such as those that use thermal boilers, green energy sources, dispatchable units, and the grid, affects the goals. As far as cost and pollution go, the microgrid design that uses both green and non-renewable energy sources is the best. When several sources are put together in a microgrid system, all goals are lowered. The suggested method is tried on a 33-bus microgrid system that is linked to the main grid and meets both power and temperature needs. (Chaduvula & Das, 2023)[84]

A mixed-integer nonlinear programming (MINLP) model utilizes a single goal approach to determine the best solution for two separate target functions: total CO2 emissions and total energy losses. Metaheuristic techniques are utilized to address the problem inside a master-slave framework. The Chu & Beasley parallel genetic algorithm (PCBGA) is employed in the master stage to address issues related to technology selection and battery energy storage system (BESS) deployment. The vortex search algorithm (VSA) is a method for addressing the junior stage Bess operation issue. This phase also defines the objective functions and utilizes a matrix-based successive approximation power flow to examine the technical and practical limitations of the mathematical model. The 33-node testing apparatus is designed to align with the production and demand attributes of Medellín, guaranteeing reliable findings. The Parallel Particle Swarm Optimizer (PPSO) and the Parallel Monte Carlo (PMC) were the two optimization techniques utilized during the master phase. Their preferred strategy is not one that they both support. The CBGA-VSA methodology surpassed alternative approaches for response quality, repeatability, and processing durations, as demonstrated by the simulation data produced for the test case utilizing MATLAB. As a result, the total yearly operating expenses were decreased. (Cortés-Caicedo et al., 2023)[87]

To reduce the microgrid's operational costs, a rank-based multiple-choice secretary algorithm (RMSA) is recommended for microgrid management. Instead of depending on accurate

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forecasting methods or full knowledge of future dynamic variables, a lightweight solution is used to make judgments in real time under uncertainty. Through dynamic pricing, the RMSA determines the best time to buy power for each assignment, allowing a microgrid to save operating costs. We do comprehensive tests on real-world data sets to show how successful our method is in complicated and varied real-world circumstances. (Xia et al., 2023)[93]

This paper talks about a unique way to use the Pelican Optimization Algorithm (POA) for Demand Response Programs (DRPs) and the best Energy Management (EM) in Microgrids (MG). To lower overall running costs and boost the MG operator's (MGO) benefits, an optimization method with several goals is used. These prices include the cost of standard generator fuel and power transaction fees. A mixed demand response program (DRP) is suggested as a way to make the Microgrid (MG) work better. IDR, or incentive-based demand response, will be used to make the microgrid more reliable and lower peak demand. In order to keep things reliable, the combination system tells people to use less during busy times. Not as many people are there during off-peak hours because standard IDR (CIDR) works better. The dynamic mixed demand response system that was mentioned takes into account both a load profile and an average load value. The usual way, on the other hand, uses set peak hours. The peak reduction percentage (PRP) shows that MG is now a lot more consistent. Using current metaheuristics and newly created algorithms to compare the modeling results shows that the suggested POA and the suggested hybrid dynamic demand response (HDDR) work well together. In order to do this, two different MG test sets are compared. Total peak hour demand goes down by 14.6% for the first test system and 7.6% for the second when HDDR with POA is used. The numbers show that the POA does a good job of fixing the EM problem. (Alamir et al., 2023)[97]

Microgrid energy exchange and the use of renewable energy resources are encouraged by a novel peer-to-peer (P2P) energy-sharing system with shared energy storage (SES). There are three primary parts to the model. A multi-objective, optimal SES allocation method is described in the first section. Reducing carbon emissions, optimizing SES benefits, and enhancing the energy sharing zone's sustainability are the objectives. A brand-new internal pricing system based on the energy supply-demand ratio is present in the second block. The last block depicts a notional optimum scheduling scheme for the ESZ. This concept aims to reduce energy costs for a multi-microgrid system (MMS) by combining residential microgrid demand response techniques with SES management practices. To solve this issue, we offer a multi-objective slime mold technique that makes use of generalized opposition-based learning and reference points. According to the simulation results, SES and energy sharing might increase ESZ's sustainability index by 9.08% while decreasing MMS's energy costs by 89.45%. The proposed P2P trading strategy could completely enable microgrids for P2P trade by firmly anchoring internal trading prices inside grid pricing. (Bian et al., 2024)[100]

S No.	Author	Year	Objective	Inspiration
1	Alessandra Parisio, et al. (Parisio et al., 2014)[1]	2014	Introduces a novel mixed integer linear methodology for the optimization and modeling of microgrids.	The proposed control framework has the potential to integrate reactive power and heat recovery capabilities in the near future.

2	Ali Maknouninejad, et al. (Maknouninejad & Qu, 2014)[2]	2014	To reduce the cost function, which is calculated by adding up all of the quadratic voltage differences at the DG nodes and other important system nodes.	Despite a number of PV limitations, this approach offers a uniform microgrid voltage profile, lower losses, and better capacitor bank operation and management.
3	Peigen Tian, et al. (Tian et al., 2016)[5]	2015	Two-tier hierarchical optimization approach for smart grid energy management systems in multi-grid topologies is proposed.	It is advised that MGC operations use two of the four scenarios that were assessed as they are thought to be cost-effective.
4	Sara Ghaem Sigarchian, et al.(Ghaem Sigarchian et al., 2016)[11]	2016	PSO has been integrated into the problem context and presented as a global optimizer.	At a comparatively cheap computational cost, it provides an excellent design option for an efficient microgrid.
5	Ali Arefi, et al. (Arefi & Shahnia, 2018)[19]	2017	By linking it to one or more appropriate nearby islanded MGs at a minimal cost, an overloaded or over-generated MG can get external support.	In the future, a suitable protocol will be devised to regulate operations in the event that the central and tertiary MG controllers' communication links fail.
6	Vahid Sarfi, et al.(Sarfi & Livani, 2018)[20]	2018	To ascertain the most economical operational strategies for diminishing generation expenses and enhancing reliability.	This economic-reliability paradigm makes the previously suggested multi-objective algorithm usable for C MGO by simplifying it.
7	Md Asaduzzaman Shoeb, et al. (Shoeb et al., 2018)[21]	2018	The proposed management system uses a multi-tiered approach to safely govern autonomous MG voltage and frequency at cheap cost.	Extensive numerical analyses in MATLAB validate the performance.
8	Shichang Cui, et al. (Cui et al., 2019)[22]	2018	To implement a two-stage energy sharing concept, a novel prosumer microgrid featuring load shifting, several storage units, and renewable energy output is suggested.	Stochastic optimization along with big data extends this research in near future.
9	Jongwoo Choi, et al. (Choi et al., 2019)[24]	2018	Maintaining high economic benefits without been affected by uncertainties in prediction.	To create a control approach that is both effective and efficient in the event of future cost reductions, taking into account both the worst-case and best-case scenarios.

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10	Mojtaba Sepehry, et al. (Sepehry et al., 2019)[32]	2019	To provide a useful tool for making decisions on the operation planning of imbalanced microgrids when uncertainty is present.	In comparison to deterministic judgments, superior performance is established in terms of average cost and worst-case uncertainty realization.
11	Elian J. Agnoletto, et al.(Agnoletto et al., 2019)[33]	2019	The OPF issue serves as the foundation for a suggested EMS for MG that can function in both grid-tied and standalone modes.	This EMS stabilizes the storage device's state of charge (SoC) and offers useful operating modes.
12	Wenzhe Su, et al. (Su et al., 2021)[43]	2020	A dual-solver framework is suggested for the optimization of microgrids, with an emphasis on energy loss and operation costs.	It provides real-time control and optimization with less delay.
13	Rodney Kizito, et al. (Kizito et al., 2020)[48]	2020	In order to lower the microgrid's total costs, it is essential to manage the frequency of network power outages brought on by grid interruptions, distribution expenses, and reverse power flow brought on by an excessive amount of distributed generating penetration inside the network.	It is practical and pertinent to the utility company, as it is financially constrained to install the DGs.
14	Seyed Mohsen Hosseini, et al.(Hosseini et al., 2021)[49]	2020	In order to reduce energy expenses and deal with a number of limitations, including the unpredictability of energy transmission between users and the grid when RESs are being generated and when user demand is high.	In the future, a reliable approach for real-time energy scheduling that incorporates a receding horizon mechanism can be implemented.
15	Nitesh Funde, et al. (Funde et al., 2020)[52]	2020	This method considers all aspects of a community, including single-family homes, commercial/office buildings, industrial, and multi-dwelling units.	It diminishes costs in a multi-microgrid system by obviating the necessity for each microgrid to engage in separate transactions with the utility grid.
16	M.F. Roslan, et al.(Roslan et al., 2021)[56]	2021	By enhancing energy storage, the Lightning Search Algorithm (LSA)	It gets the most out of the microgrid system's spread-out energy resources to make a long-lasting power system with a

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			increases power delivery while reducing expenses.	fast convergence rate and short working time.
17	Bishwajit Dey, et al. (Dey et al., 2022)[69]	2021	Developing a low-voltage, grid-connected microgrid system is less expensive when renewable energy is used.	The generation cost is reduced by employing a market pricing strategy that is based on Time of Usage (TOU).
18	Kavitha V, et al. (V et al., 2022)[70]	2021	To minimize production costs and ensure that the microgrid and local controller communicate seamlessly.	It is capable of enhanced optimization, as well as a swift convergence rate and fewer iterations than conventional existing algorithms.
19	Abba Lawan Bukar, et al. (Bukar et al., 2022)[76]	2022	It proposes a metaheuristic optimization search method (MOST) for the scaling of self-sufficient microgrids and a rule-based energy management system.	This configuration reduces CO2 emission and fuel consumption in comparison to fossil fuel-based diesel generator.
20	Gokul Sidarth Thirunavukkarasu, et al. (G. S. Thirunavukkarasu et al., 2022)[80]	2022	Examination of numerous optimization methodologies for energy management concerns in microgrids.	MIP is the most frequently employed algorithm; however, metaheuristics and MAS are more efficient. Forecasting and demand management are not frequently implemented with AOT.
21	Samaniba Imchen, et al. (Imchen & Das, 2023)[82]	2023	Proposes an O-KKO method for making separated microgrids for distributed generation (DG) that is based on opposition learning.	The cost and emission of hazardous substances are minimized in this technique, as evidenced by comparative results with other algorithms.
22	Hemanth Chaduvula, et al. (Chaduvula & Das, 2023)[84]	2023	Fuzzy technique and PSO combine and address cost, emissions, and energy loss.	One can determine the ideal storage system size and use a thermal storage device to store microgrid heat.
23	Brandon Cortés-Caicedo, et al.(Cortés-Caicedo et al., 2023)[87]	2023	To create an optimization strategy aimed at lowering CO2 emissions and energy losses while using fossil fuels at the substation node.	The topic of microgrid operation, technology selection, and BESS implementation is covered.

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24	Chunqiu Xia, et al. (Xia et al., 2023)[93]	2023	To reduce MG's running costs in the face of several uncertainties, a new, lightweight method is suggested.	The outcomes of several studies carried out on real-world data sets show how successful it is in complicated and varied real-world circumstances.
25	Nehmedo Alamir, et al. (Alamir et al., 2023)[97]	2023	To optimize benefits for the MG operator while minimizing overall operating costs, including as production and transaction costs.	It is possible to identify and evaluate demand and renewable energy generation uncertainties and their effects on EM's performance in MG.
26	Yifan Bian, et al. (Bian et al., 2024)[100]	2023	To enable flexible energy trading across microgrids and make the most of RES.	MG is encouraged to participate in peer-to-peer trading as it can secure the internal trade prices inside the grid pricing.

4.Role of Artificial Intelligence techniques in Microgrids

This study analyzes the design aspects and performance challenges, as well as summarizes and compares a variety of performance metrics and optimization algorithms in terms of their efficacy and convergence time in achieving system objectives. Particle Swarm Optimization's advantageous convergence time has encouraged its use with other methods to tackle microgrid optimization problems. The research investigates the methods of information dissemination and consensus, employing the average-consensus algorithm to accomplish equilibrium asynchronously over multiple iterations. The focus of the conversation is a multi-agent system that is designed to restore multiple microgrid services. (Tazi et al., 2020)[29]

A diverse array of secondary control strategies, such as virtual voltage control systems, multi-agent system (MAS) control, and dynamic current sharing schemes, have been developed to regulate voltage. Investigations are undertaken about power management for Energy Management Systems (EMS), modular-based energy routers (MBER), and other integrated control systems. It demonstrates the various control mechanisms employed to alleviate the effects of communication delays. The Takagi-Sugeno model prediction, Lyapunov-Krasovskii functional stability, and linear matrix inequality (LMI) can be utilized to reduce communication time. A variety of control mechanisms have been investigated to attain impedance matching. The components include the linear programming method, the nonlinear disturbance observer (NDO) feedforward correction, hybrid potential theory, and linear system analysis of polyhedral uncertainty. It analyzes the merits and demerits of certain control systems. Furthermore, further study is scheduled to investigate the stability and hierarchical management of DC microgrids and groups of DC microgrids. (Han et al., 2019)[35]

To investigate strategies for monitoring grid-connected microgrid power systems utilizing reinforcement learning (RL) methodologies. A thorough model of the optimization environment is essential to get the optimal conclusion when utilizing conventional optimization methods, including numerical and soft computing approaches. Nonetheless, reinforcement learning is not essential. The incorporation of microgrids into infrastructure complicates electricity management. We meticulously assess the effectiveness of reinforcement learning methodologies in tackling these difficulties. This research emphasizes the need to improve multi-agent reinforcement learning methods for power distribution in networked microgrids. The paper culminates with recommendations for subsequent research. These include merging intrinsic and extrinsic incentive systems, applying transfer learning to improve reinforcement learning performance in challenging power system scenarios, and prioritizing experience replay to govern microgrid power flow after a disaster. (Arwa & Folly, 2020)[42]

The proposed solution considerably enhances the power system's capacity to reestablish a stable operational state in the event of a minor physical interruption. The MALANN combines an artificial neural network (ANN) with the modified antlion optimization method (MALO). This controller contains two loops: an internal current loop and an external power loop. The MALO technique produces a dataset with projected proportional integral (PI) gain characteristics. Because the ANN was trained on the enormous MALO dataset, its expected performance is guaranteed to be consistent across all system operating conditions. The findings are analyzed in MATLAB/Simulink for two test situations and compared to several problem-solving methodologies, including ant-lion optimization and the fundamental methodology. The stability study was rather accurate, and the findings show that the controller ensures system reliability. (Venkatesan et al., 2021)[44]

Reinforcement learning (RL) is used to establish a residential microgrid (RM) online without the need for a prediction model for future solar or wind power sequences. Examine how the RM scheduling conundrum is resolved by Model-Based Reinforcement Learning, namely MuZero. When paired with mathematical optimization techniques, a model-based reinforcement learning agent uses long short-term memory (LSTM) units to load sequences and retrieve information from prior renewable production. Using a trained model to solve an optimal power flow sub-problem, Monte-Carlo tree search (MCTS) finds the best solution at each time step. This method can make operational choices in real time without the need for a prediction model. Numerical simulation results show how effective the suggested approach is. (Shuai & He, 2021)[45]

This study presents an adaptive security strategy for the next green power distribution and management system. Convolutional neural networks (CNN) are utilized to evaluate voltage and current in lines inside multidimensional arrays, as well as to classify pictures. The suggested CNN was improved via the hyperparameter and design optimization procedure of the Gorilla Troops Optimization (GTO) approach. This approach utilizes the three suggested CNN-GTO security plan models to consolidate problem categories, pinpoint defect locations, and detect system issues. A communication technique has been developed to facilitate the sharing of data, information, and alarms among the many components of the FREEDM system. This strategy is tested using a simulated FREEDM microgrid system that includes several failure scenarios. This method accurately discovers, analyzes, and classifies dietary inadequacies in the FREEDM system. The current study focuses on support vector machines, wavelet-based convolutional neural networks, fuzzy logic approaches, and classic convolutional neural networks. Improved CNN-based GTO models can achieve an overall accuracy rating of 99.37% for defect detection, 99% for defect classification, and 98.2% for defect localization. (Hatata et al., 2022)[73]

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Optimal power flow, peak reduction, and optimal network designs are the three categories into which microgrid challenges can be divided after assessing the issues and outlining the most recent metaheuristic approaches. Blockchain technology and reinforcement learning are essential for decentralization, cybersecurity, and microgrid energy management. Metaheuristics (e.g., evolutionary, swarm, physics-based, human-based, hybrid, and other methods), learning definitions (e.g., model-based control, reinforcement learning, fuzzy logic), modeling techniques and formulations, optimization objectives, solution algorithms, and dependable decentralized blockchain approaches are all accessible. The results demonstrate that microgrid management systems can be developed in a number of ways based on system size, grid connectivity, technology, capital expense, and automation levels. We will be able to tackle the upcoming difficulties in the creation of artificial intelligence applications for microgrids powered by renewable energy sources using both conventional and next-generation technology. (Tajjour & Singh Chandel, 2023)[81]

ANN, ML, and DL are used to forecast load demand and renewable energy over four-time horizons: ultra-short, short, medium, and long. It evaluates microgrid forecasting techniques and instruments by looking at recent developments in ANN, ML, and DL. To do this, we will conduct a comprehensive investigation, which will involve selecting a sizable database from the Web of Science and compiling pertinent research publications. In order to create a robust and durable microgrid ecosystem, these strategies outline the benefits and drawbacks of using ANN, ML, and DL to anticipate renewable energy and microgrid load demand. (Wazirali et al., 2023)[83]

S No.	Author	Year	Objective	Inspiration
1	Khadija Tazi, et al. (Tazi et al., 2020)[29]	2019	An overview of MAS for microgrid control and management is provided.	Various challenges and research gaps are mentioned for future research.
2	Yang Han, et al. (Han et al., 2019)[35]	2019	The authors talk about better main control strategies to increase present sharing accuracy.	The advantages and disadvantages of different control systems are examined, along with future directions for research into hierarchical control and stability in DC microgrids and clusters.
3	Erick O. Arwa et al.(Arwa & Folly, 2020)[42]	2020	Power management in grid-tide MG using reinforcement learning (RL) algorithms.	By combining internal and extrinsic reward processes, transfer learning is used to enhance the reinforcement learning results of complicated power systems. In the wake of a disaster, microgrid power flow is managed through the use of priority-based experience replication.

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4	Anantha Krishnan Venkatesan, et al. (Venkatesan et al., 2021)[44]	2020	To enhance the power system's ability to restore operational conditions following minor physical disturbances.	Results verify the accuracy of stability analysis and the controller offer a reliable system operation.
5	Hang Shuai, et al. (Venkatesan et al., 2021)[45]	2020	The online scheduling of a residential microgrid by utilizing reinforcement learning without the use of a predictive model for future photovoltaic/wind and load power sequences.	It can consecutively execute operational decisions online without depending on a predictive model.
6	Ahmed Y. Hatata, et al. (Hatata et al., 2022)[73]	2022	For the upcoming FREEDMS system, which stands for renewable electric energy delivery and management, this article suggests an AP mechanism.	In defect identification and classification, it outperforms CNNs, fuzzy logic, SVMs, and CNNs based on wavelet transforms.
7	Salwan Tajjour, et al. (Tajjour & Singh Chandel, 2023)[81]	2023	An examination of the methods of artificial intelligence (AI) and blockchain technology for the purpose of creating an energy management system that is both self-sufficient and secure.	Future AI application challenges are identified for both conventional and renewable energy based microgrids.
8	Raniyah Wazirali, et al. (Wazirali et al., 2023)[83]	2023	Evaluating the methods and applications of the most current advances in ANN, ML, and DL for microgrid prediction is the goal.	To ascertain the most efficacious approach for a microgrid ecology that is both versatile and sustainable.

5. New designing and developments of Microgrid using advanced metaheuristic techniques.

In order to transform the conventional grid network into a smart grid network, this study suggests efficient methods for assessing distribution-based energy management strategies and microgrid energy management systems. Distributionally robust optimization (DRO), a method for controlling and reducing the risks related to power shortages or excess supply from renewable sources, is also covered in this study. (Onsomu et al., 2024)[103]

A new Dynamic Batching EMS approach is proposed in this research for effective energy management in a multi-microgrid network. This approach looks at islanded and grid-connected operational modes to maximize the MMG network. By optimizing resource allocation, enhancing individual microgrid privacy, and lowering running costs inside the MMG network,

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it exceeds present approaches of centralized, distributed, and layered management systems. (Albert Paul Arunkumar & Selvakumar, 2024)[118]

This research presents a multi-agent reinforcement learning (MARL) collaborative power dispatch technique for battery energy storage systems (BESSs). The method aims to track power fluctuations in the power conversion chain (PCC) brought on by the unpredictability of PV power generation. The results of the simulation demonstrate that the recommended approach performs better than both the alternative baseline MARL and conventional optimization methods. (He, Li, et al., 2024)[120]

This study explores the best methods for mapping and assessing the literature on hybrid energy projects with battery storage, with a focus on wind and solar energy. Throughout the literature evaluation, the PRISMA criteria were adhered to, guaranteeing a comprehensive and rigorous approach and boosting the reliability of the results by increasing the transparency of the sample selection procedure. (Barbosa et al., 2024)[123]

An overview of the current ideas and strategies for increasing microgrid efficiency using renewable energy. The optimization process is based on the strategic coordination and control of energy resources such as wind turbines, solar photovoltaic (PV) systems, and energy storage systems (ESS). To lower operational costs, greenhouse gas emissions, system stability, and power supply reliability, advanced optimization techniques such as model predictive control (MPC), mixed-integer linear programming (MILP), and heuristic algorithms are employed. Machine learning and artificial intelligence have made decision-making substantially more effective. Flywheels and batteries are examples of energy storage systems (ESS) that act as reservoirs, storing surplus energy during peak generation and releasing it during peak consumption. Demand response (DR) solutions in microgrids aim to equilibrate supply and demand, mitigate peak load, and improve the grid's overall resilience, thereby strengthening optimization initiatives. (Chijioke Paul Agupugo et al., 2024)[124]

Autonomous planning and real-time operation are made possible by the comprehensive and robust design of a multi-energy system (MES). We provide an all-inclusive and flexible daily planning model that incorporates important operational and uncertainty constraints together with adjustable optimization. The concept uses photovoltaics, wind turbines, combined heat and power (CHP) units, energy storage systems (ESS), electric vehicles (EV), electric furnaces, and power-to-gas (P2G) plants to meet the needs for natural gas, electricity, and heating. The objective is to reduce operating expenses while still meeting thermal and electrical requirements because renewable energy sources are uncertain. It entails creating a two-phase, dependable, and flexible optimization model that outlines the techniques for capacity restrictions, energy balance, and demand responsiveness. (Y. Wang & Li, 2024)[129]

A summary of the latest developments in optimizing certain hybrid renewable energy systems via software-based tools, artificial intelligence (AI), hybrid algorithms, and traditional approaches. AI-driven systems exhibit more accuracy and provide swifter replies, albeit their considerable disadvantages. Utilizing a hybrid optimization technique enables the more efficient, frequent, and effective resolution of difficulties via the integration of many methodologies. Furthermore, an array of optimization technologies is employed. HOMER is a commonly utilized computer tool owing to its straightforwardness. This study examines the

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present and developing landscape of optimization methods for HRES applications, allowing researchers to identify the most suitable course of action according to their individual needs. (M. Thirunavukkarasu et al., 2023)[131]

Maximum power point tracking (MPPT) in a grid-connected solar system under partial shade is accomplished by using a neuro-fuzzy controller. The Gravity Search Algorithm (GSA) is used to determine the Global Maximum Power Point (GMPP). The suggested approach not only outperforms current power production techniques but also accurately identifies the ideal power point in both uniform and partial shadow scenarios. It operates quickly as well. (Danyali et al., 2024)[133]

A method for handling dynamic dispatch issues in microgrids is presented. Renewable energy sources (RES), like solar and wind power, are part of the algorithm. Efficiency can be assessed using four distinct testing scenarios. This study examines two CEED approaches, fractional programming (FP) and penalty pricing factor (PPF), with an emphasis on RES integration, to determine the best strategies for lowering emissions and raising revenue in an autonomous microgrid context. Economic load discharge (LD), emission dispersion (EMD), and CEED will be covered in the following sections. The SNS technique's ability to manage challenging and non-convex dynamic dispersion conditions, such as ramp rate limits and valve point loading (VPL) implications, is tested in the next two test cases. Renewable energy sources (RES) diminish industrial expenses and emissions. (Spea et al., 2024)[135]

A new multi-objective approach is used in short-term microgrid scheduling to lower negative emissions and operating costs. Designed to provide Pareto optimal solutions while reducing pollution and increasing economic efficiency, a Chaotic Self-Adaptive Sine Cosine Algorithm (CSASCA). This method surpasses traditional SCA in tackling multi-objective optimization challenges, such as microgrid scheduling, by attaining superior convergence, improved exploration, reduced parameter sensitivity, and effective constraint management. (Karthik et al., 2024)[137]

This study looks into how advanced machine learning techniques, especially Support Vector Regression (SVR), could be used to make grid-connected microgrids that use green energy sources more reliable and efficient. Power generation predictions are more accurate with this method because it takes into account thorough historical data on energy production, changing grid conditions, and specific weather trends. Improving the balance between supply and demand and making green energy sources less unpredictable and irregular makes the grid more stable. It makes it easier to add green energy sources to the microgrid in a way that won't harm the environment. This makes the infrastructure more reliable, efficient, and clean. The results support future progress in energy management by making smart energy systems that can adapt to new situations better. (R. Singh et al., 2024)[138]

In order to plan the DGs of a dynamic system and minimize pollutant emissions while achieving low active power generation costs, this research proposes a hybrid optimization technique that is both dependable and effective. In assessing costs and emissions, several fitness functions, including the use of wind, demand-side management (DSM), and other combined economic emission discharge (CEED) technologies, are taken into account.

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Numerical findings verify the suggested CSA¬JAYA's cost and emission decrease when compared to the list of algorithms in the study. (Misra, Panigrahi, et al., 2024)[139]

The analysis and discussion of fast charging techniques with two sources, solar and utility, are presented. Techniques for fast charging that utilize utility and solar power sources are also addressed. The paper also examines and debates the approaches employed in Fast Charging Stations (FCS) and the advantages and disadvantages of employing utility and solar power sources. The challenges and issues that are currently associated with electric vehicles (EVs) are identified. The survey concludes that the development of FCS that integrate both grid and solar power sources is essential to promote the widespread adoption of EVs, thereby providing a sustainable transportation system. (Bishla & Khosla, 2024)[141]

The many uses of the Internet of Things are covered in this essay, along with its advantages and disadvantages in terms of the environment, society, and economy. Integrating renewable energy, automating power plants, installing smart safety equipment, and creating smart houses with occupancy sensors and smart meters are a few advantageous applications. (Majhi & Mohanty, 2024)[142]

The unpredictable and intermittent character of renewable resources, particularly solar and wind power, is addressed by a novel optimization model that is based on online reinforcement learning. The findings indicate that this methodology is not dependent on conventional mathematical models and is capable of effectively accommodating the intricate constraints and uncertainties associated with wind power-photovoltaic energy storage systems (WPESS). In addition to reducing the cost, its computational efficacy surpasses that of the deep Q-network (DQN) and model predictive control (MPC) algorithms. (Meng et al., 2024) [144]

A dynamic, interactive simulation of a real-world physical system is its digital equivalent. It is produced by fusing machine learning, simulations, and real-time data. By creating a digital replica of microgrids, users can increase operating efficiency, track performance in real time, and anticipate issues. It enhances energy management strategies, encourages predictive maintenance, reduces downtime, and lengthens equipment lifespan by identifying different flaws. Simulation results can evaluate a variety of scenarios, such as fluctuations in equipment performance, altering weather conditions, and variable energy demands. (Kelvin Edem Bassey et al., 2024)[147]

It is proposed that microgrids employ a control technique to maximize capacity configuration by controlling distributed power sources and energy storage. The Ant Lion Optimizer (ALO) improves population variation and convergence by combining chaotic mapping and dynamic weight components. An independent microgrid case study reveals that this control technique and improved ALO give the optimum answer for the microgrid capacity allocation model, demonstrating the superiority of improved ALO. (Liu, 2024) [148]

This paper provides an overview of the existing reinforcement learning methodologies addressing sustainable energy issues. The pertinent sustainability difficulties are enumerated, characterizing their modeling as a reinforcement learning problem and outlining the solution methodologies currently available in the literature. The predominant topics in reinforcement learning that emerge within sustainability include multi-agent systems, offline learning, and

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safe reinforcement learning. This survey offers a comprehensive overview of reinforcement learning techniques for sustainable energy, which is crucial for the energy transition. (Ponse et al., 2024)[152]

S No.	Author	Year	Objective	Inspiration
1	Obed N. Onsomu, et al. (Onsomu et al., 2024)[103]	2024	Distributionally robust optimization (DRO), a technique for controlling and lowering the risks related to power outages and renewable energy overstock, is presented in this study.	DRO method has natural ability to consider multiple constraints using more than one way and distribution probability functions and also perform better as compared to the existing methods in the review.
2	C.P. Albert Paul Arun kumar, et al. (Albert Paul Arunkumar & Selvakumar, 2024)[118]	2024	Evaluates the proposed technique in connected and isolated modes utilizing four microgrids. Modeling uses Mixed Integer Linear Programming.	With or without BESS, islanded mode optimizes situations.
3	Wangli He, et al. (He, Li, et al., 2024)[120]	2024	This study uses multi-agent reinforcement learning to help Battery Energy Storage Systems (BESS) dispatch electricity collaboratively. This method reduces PCC power oscillations caused by PV power generation variability.	Through simulated studies using the IEEE-33 and IEEE-141 bus systems, the scalability and efficacy of the suggested approach in minimizing operating costs and eliminating PCC power and voltage swings are confirmed.
4	Aglaucibelly Macie Barbosa, et al. (Barbosa et al., 2024)[123]	2024	The study divided the 54 optimization strategies into five groups to demonstrate their diversity and complexity.	To improve low-carbon energy and sustainable development, investment for battery-storage hybrid energy systems is critical.
5	Chijioke Paul Agupugo, et al. (Chijioke Paul Agupugo et al., 2024)[124]	2024	An analysis of the most recent methodologies and developments in improving microgrid operations using renewable energy sources is presented.	To achieve desired objectives, MPC, MILP, and heuristic algorithms dynamically alter energy generation and distribution based on current conditions.
6	Yang Wang, et al. (Y. Wang & Li, 2024)[129]	2024	The optimization problem is resolved using a novel modified Slime Mold Algorithm (SMA), which exhibits superior computational efficiency and convergence in	A multi-energy system (MES) that is both comprehensive and resilient, and is intended for real-time implementation and independent planning.

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			comparison to conventional meta-heuristics.	
7	M. Thirunavukkarasu, et al. (M. Thirunavukkarasu et al., 2023)[131]	2024	A detailed review of the current methods for optimizing HRES using software, hybrid algorithms, artificial intelligence and traditional methods.	Offers an overview of the present and developing optimization methodologies for HRES applications, facilitating the selection of the best suitable strategy based on specific requirements.
8	Saeed Danyali, et al. (Danyali et al., 2024)[133]	2024	Presents a novel neuro-fuzzy controller utilizing the Gravity Search Algorithm (GSA) to enhance MPPT in a grid-connected solar system subjected to partial shade situations.	Because of its adaptive capabilities, the neuro-fuzzy controller responds to dynamic shading fluctuations and ensures a steady and optimum power output.
9	S. R. Spea, et al. (Spea et al., 2024)[135]	2024	This study comes up with a new way to solve the dynamic dispatch problems in microgrids using social network search (SNS) and RES like wind and solar systems.	The two CEED methodologies Fractional programming (FP) reduces pollution emissions, while the penalty price factor (PPF) decreases generation costs.
10	N. Karthik, et al. (Karthik et al., 2024)[137]	2024	The Chaotic Self-Adaptive Sine Cosine Algorithm (CSASCA) balances cost and pollution while determining the optimal Pareto solutions.	For MG scheduling, this provides better exploration, better convergence, efficient constraint management, and less parameter sensitivity.
11	Arvind R. Singh, et al. (R. Singh et al., 2024)[138]	2024	It employs cutting-edge machine learning techniques such as Support Vector Regression (SVR) to improve system dependability and efficiency. Electricity generation projections take into account complex weather patterns, dynamic grid circumstances, and historical energy output data.	This algorithm offers enhanced accuracy, reliability, and cost-efficiency for renewable energy grid integration solutions.

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12	Srikant Misra, et al. (Misra, Panigrahi, et al., 2024)[139]	2024	This method produces dynamic distributed generators (DGs) with low active power generating costs and decreased pollutant emissions using a hybrid optimization tool.	Numerical findings shown that the proposed CSA¬JAYA significantly reduced both cost and emission when compared to previous methods.
13	Sandeep Bishla, et al. (Bishla & Khosla, 2024)[141]	2024	The concentrate of the article is on the rapid recharge methods that utilize solar and grid power sources.	To solve sustainable transportation issues and hasten the deployment of electric vehicles (EVs), quick charging solutions that integrate solar and grid power sources are needed.
14	Abhilash Asit Kumar Majhi, et al. (Majhi & Mohanty, 2024)[142]	2024	This review presents the transformative role of IoT in power systems, focusing on its impact, growth opportunities and the need to address existing challenges.	It gives a detailed exploration of the complex dynamics surrounding IoT in the power sector, leading to an informed decision-making and future developments.
15	Qinglin Meng et al. (Meng et al., 2024)[144]	2024	Introduces a novel optimization model based on online reinforcement learning.	Helps in effective power tracking and reduction of storage charging and discharging.
16	Kelvin Edem Bassey, et al. (Kelvin Edem Bassey et al., 2024)[147]	2024	Digital twins that faithfully replicate reality are produced using machine learning, simulations, and real-time data. It displays a real computer system.	DTT improves grid resilience, energy management, predictive maintenance, and operational efficiency by providing a comprehensive, real-time virtual model.
17	Rui Liu (Liu, 2024)[148]	2024	An MG control technique that successfully manages energy storage and dispersed power sources in order to optimize energy configuration.	This control approach offers a great answer to the microgrid capacity allocation model when paired with an improved ALO algorithm.
18	Koen Ponse, et al. (Ponse et al., 2024)[152]	2024	This paper bridges the two research communities i.e. energy and machine learning.	Offers a comprehensive examination of reinforcement learning techniques applicable to sustainable energy, which could be crucial in the energy transition.

This study examines and discusses the basic research that forms the basis of the GTO. It looks at possible ways to make the GTO behave better, paying special attention to making sure the search area's shape complies with actual optimization problems. Additionally, it presents the GTO solver, explaining how to identify, organize, and use it in various optimization settings. It

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also gives a detailed analysis of convergence behavior and tackles the main problem with the GTO model. Outlines the study's principal findings and gives recommendations for future revisions and improvements to the GTO. Opposition-based learning (OBL) enhances the convergence and exploitation of optimization algorithms. Throughout the optimization process, this link guarantees that the capacity for exploration and exploitation is balanced. The GTO with OBL is investigated and detailed in a section that covers a wide range of applications and scenarios. (Hussien et al., 2024)[101]

This research proposes an optimal energy scheduling technique for microgrids with an enhanced Generative Adversarial Imitation Learning (GAIL) algorithm. This approach maximizes rewards for superior tactics while improving training stability by utilizing the Wasserstein distance, generative adversarial theory, and the PPO algorithm. The case study results demonstrate that the suggested technique outperforms the GAIL and PPO algorithms for speed, convergence, and operational expenses. (K. Wang et al., 2024)[104]

In order to simulate the most efficient functioning of microgrids, this research presents a complex bi-level optimization algorithm. While the bottom level maintains load balance by controlling distributed generation and putting load reduction initiatives into place, the higher level aims to maximize the profitability of both MGs and Distribution Companies. The best pricing techniques for power transactions are influenced by a number of elements at the executive level, including as market prices, demand response initiatives, and variations in wind speed. In addition to considering the goals and limitations of each, this research offers a succinct summary of the complex interactions between MGs and DCs. Because it offers a more accurate depiction of the decision-making process in retail electrical markets, this approach offers crucial information on the best way for MGs to operate inside the DCs setting. (Helmi et al., 2024)[107]

The best method for controlling microgrids using hybrid renewable energy sources (HRES) is reserve provisioning. This is accomplished by using the particle swarm optimization technique. This approach effectively charges and discharges BESS while maintaining the reserve margins essential to meet crucial demands during grid and renewable energy source failures. The volume of power supplied to the system rises on both sunny and partially overcast days. Although BESS is sometimes charged with additional renewable energy or at low-cost off-peak hours, power is solely acquired during these intervals. As a result, the microgrid functions at optimal efficiency and produces a significant return. (Mquqwana & Krishnamurthy, 2024)[116]

Through proposed flexible energy-use legislation, this study presents a strategy for optimizing community energy systems that concurrently optimizes microgrid operational scheduling and factors for energy supply and demand. It recommends a number of simultaneous changes that lower or realign energy use at peak hours, with an average yearly benefit. In an attempt to maximize the benefits of energy, investment, society, and the environment, it also talks about the jellyfish search algorithm (JSA). The findings support the annual average advantages under various conditions, such as integrating flexible energy-use laws with microgrid operation schedule. (Zhang et al., 2024)[119]

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To lower production costs and DER emissions, a low voltage grid-connected microgrid should use a demand side management (DSM) strategy that makes use of hybrid intelligence techniques. Five distinct microgrid scenarios are examined, each with a different mix of market pricing, grid involvement strategies, and demand response systems. The suggested method, which integrates DSM, is better since it lowers production costs and emissions for different load models, according to a comparison of the results with previously published research. (Misra, Dey, et al., 2024)[121]

A novel approach to energy management in multi-energy microgrids (MEMG) is enhanced multi-agent federated reinforcement learning. To optimize the MEMG system while accounting for the financial gains of different P2P trading market participants, a model was created. A new federated attention-based multi-agent deep deterministic policy gradient (FA-MADDDPG) framework is proposed, specifically for real-time scheduling optimization of MEMG systems, to address gradient instability and low learning efficiency in traditional federated reinforcement learning using the FedAvg federation strategy. An innovative method for figuring out the State of Charge (SoC) balance in distributed energy storage both before and after scheduling is directional noise-based agent exploration. This method exhibits superior convergence, enhanced energy scheduling capabilities, and reduced economic costs relative to the MADDPG and federated MADDPG methods. (Xiaowei Pu et al., 2023)[125]

The proposed solution employs cloud computing to enable microgrid operation and cost-effective power management. The framework controls distributed generators at the cloud computing layer by coordinating a multi-objective optimization process. The evolutionary algorithm enables cost-effective DG operation within voltage constraints, ensuring low cost, minimal losses, and optimal voltage operation. The control layer improves system resilience by implementing assured cost management and $H\infty$, as well as controlling DGs' dynamic performance. Ten-bus test systems can be used to determine the efficacy of the proposed control mechanism. (Cai et al., 2024) [128]

This paper proposes two sophisticated meta-heuristic algorithms, Sand Cat Swarm Optimization (SCSO) and Siberian Tiger Optimization (STO), for the development of home energy management (HEM) systems. Artificial intelligence monitors and adjusts the inbuilt STSC algorithm to enhance home energy consumption. By effectively reducing expenses, it enhances the overall efficiency of home power supply systems. It employs artificial intelligence (AI) to integrate adaptable demand solutions with renewable energy sources, therefore reducing carbon emissions. (aldhahri et al., 2024) [130]

The Enhanced Artificial Rabbits Optimization Algorithm (IAROA) is utilized to develop a sophisticated unit that manages the operations and costs of multi-source microgrids. This unit enhances operational efficiency by considering energy expenditures, industrial capacity, and real load demand. The appropriateness and viability of the suggested technique for SMG's demand management system are evidenced by the optimization outcomes derived from the Whale Optimization Algorithm (WOA) and Honey Badger Algorithm (HBA). The results confirm the improved effectiveness of the suggested technique. (Alhasnawi et al., 2024) [132]

The P and M70 optimization techniques for enhancing microgrid performance in islanded mode are examined in this work. The objective is to lower industrial costs while maintaining a steady

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supply of energy. To maximize the use of renewable energy while lowering petroleum use, Algorithm P prioritizes low-capacity diesel generators, battery storage, and photovoltaic (PV) installations. In contrast, M70 employs a heuristic approach to managing energy resources in real time. The simulation results suggest that both approaches significantly improve microgrid efficiency, with the M70 strategy being more adaptive and cost effective. This research will help to develop dependable and scalable energy management technologies in preparation for the forthcoming smart grid rollout. (Žigman et al., 2024)[146]

This paper claims that by preserving the equilibrium between energy production and consumption, integrated energy management fosters both environmental and economic sustainability. Machine learning (ML) techniques are used in energy management to enhance load estimation. We analyze and evaluate multi-level perceptron regression, K-fold cross validation, random forest regression, and decision tree regression using real-world data. The Random Forest Regression model performs better than the other models in terms of accuracy and predictive power, according to the R-squared (R2) score. (Mallala et al., 2024) [151]

S No.	Author	Year	Objective	Inspiration
1	Abdelazim G. Hussien, et al. (Hussien et al., 2024) [101]	2024	Artificial Gorilla Troops Optimizer (AGTO) is analysed.	Highlight the investigation's main conclusions as well as the possibility of further advancements and changes within the framework of the GTO.
2	Kuo Wang, et al. (K. Wang et al., 2024)[104]	2024	The microgrid uses both Generative Adversarial Imitation Learning (GAIL) and the Wasserstein distance to optimize energy scheduling.	This leads to speedier operations, a 1.3% and 2.6% gain in convergence, and a 7.13% and 15.05% decrease in operating expenses in economic dispatch when compared to GAIL and PPO.
3	Hamid Helmi, et al. (Helmi et al., 2024)[107]	2024	While taking into account the objectives and constraints of both, paper illustrates the intricate interactions between MGs and DCs.	Gives a clear picture of how decisions are made in retail energy markets and how MGs should function best in the setting of DCs.
4	Manduleli Alfred Mquqwana, et al. (Mquqwana & Krishnamurthy, 2024)[116]	2024	The proposed system charged and discharged the BESS efficiently while maintaining reserve margins for important loads when the grid and renewable energy sources are down.	Sunny days increased grid power sales by 58% and rainy days by 153%.

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5	Chengyu Zhang, et al. (Zhang et al., 2024)[119]	2024	The aim is to maximize the returns on investments in the environment, energy, and society by using computer methods like the jellyfish search algorithm (JSA).	The optimal combination of variable energy-use limitations and microgrid operation scheduling yields annual average profits that range from 15.655% to 18.016% in a various situations.
6	Srikant Misra, et al. (Misra, Dey, et al., 2024)[121]	2024	Demand response strategies, power market pricing, and grid connectivity for microgrid systems are tested in five scenarios. The outcomes justify the savings.	For different microgrid load models, environmentally constrained economic dispatch provides a better balance between the lowest generating cost and emissions.
7	Xiaowei Pu, et al. (Xiaowei Pu et al., 2023)[125]	2024	The MEMG system's unique energy management technique is based on enhanced multi-agent federated reinforcement learning technology.	The suggested approach reduces the economic cost by 13.57% and 10.22%, respectively, and has superior convergence and energy scheduling capabilities.
8	Cong Cai, et al. (Cai et al., 2024)[128]	2024	This paper introduces a cloud computing-based framework structure for the economic operation and voltage regulation of microgrids.	A multi-objective optimization technique coordinated across many cloud computing tiers is used to manage DGs. We can prevent losses, save money, and maintain a steady voltage by using a genetic algorithm.
9	Eman Ali aldhahri, et al. (aldhahri et al., 2024)[130]	2024	The study introduces an artificial intelligence-based STSC system to monitor and enhance household energy utilization.	This investigation emphasizes the potential for AI-driven solutions to optimize residential energy consumption in an environmentally friendly and efficient manner.
10	Bilal Naji Alhasnawi, et al. (Alhasnawi et al., 2024)[132]	2024	A smart energy management unit regulates a range of energy resources, lowering the microgrid's operational costs.	The Enhanced Artificial Rabbits Optimization Algorithm (IAROA) optimizes operational costs using energy prices, capacity needs, and production capacities. It uses the HBA and WOA.
11	Dubravko Žigman, et al. (Žigman et al., 2024)[146]	2024	A comparison of the two optimization techniques, P and M70, used to maximize microgrid performance in islanded mode.	It creates scalable and resilient EMS for the implementation of smart infrastructures in the future. Both algorithms enhance the efficacy of MG; however, M70 exhibits superior

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				adaptability and cost efficiency in dynamic environments.
12	Balasubbareddy Mallala, et al. (Mallala et al., 2024)[151]	2024	Describes how integrated energy management promotes economic and environmental sustainability by balancing energy generation and consumption.	Integrating real-time data streams and sophisticated analytical methods, like deep learning and reinforcement learning, may provide more dynamic and adaptable energy management solutions.

This study suggests an energy balancing and burden reduction method to increase the stability of hybrid microgrid systems during islanding. Prioritizing important tasks, employing resources wisely, and, if needed, putting an effective load-reduction plan into action can all help to increase system stability. An analytically verified capacity-limiting mechanism serves as the foundation for this tactic. It guarantees that blackouts are prevented even as the number of loads rises since it takes load into account and offers a workable substitute. The energy storage technique guarantees maximal DC sub-grid power generation when off-peak grid electricity is used. A hybrid AC/DC microgrid constructed using IEEE-33 bus technology demonstrates the efficacy of this approach. The simulation results show that MILP-based load reduction preserves system stability and prevents unexpected breakdowns. (S. Sarwar et al., 2024)[114]

A new four-level min-max-max-min resilient optimization (RO) model with worst-expectation and probability is developed for a multi-energy microgrid (MEM), accounting for source and demand uncertainty. It becomes unworkable to separate the original Four-level model into a major issue and a subordinate problem (SP). The Karush–Kuhn–Tucker criteria allows one to reformulate a sequential programming problem into a form fit for resolution. The comprehensive four-level RO may be addressed utilizing the column and constraint generating (C&CG) methodology. Finally, the suggested paradigm and solution strategy are illustrated via successful case examples. The results demonstrate that the convergence behavior is acceptable. The MEM can diminish carbon emissions through the use of carbon capture technology and carbon trading mechanisms. (He, Wu, et al., 2024)[115]

The district heating and cooling networks that integrate multiple grid connections, effective energy management, and interdisciplinary control mechanisms are briefly summarized in this study. To accomplish district energy sharing and regional energy balancing, an energy migration architecture based on intercity mobility is suggested. Demand forecasting, energy allocation, surrogate models for uncertainty analysis and optimization, geometric and operational parameter design, and the influence of machine learning techniques on energy planning and optimization are just a few of the many subjects covered in this study. A district energy network is made up of several state-of-the-art energy converters that produce renewable energy locally, recover waste heat from centralized power plants, and distribute renewable

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energy. Energy congestion between renewable and hybrid grids, the need to set benchmarks for selecting the best energy storage options given inherent variations and regional circumstances (such as geography and climate), optimizations using complex algorithms, and multi-criteria decision-making to encourage stakeholder participation are just a few of the numerous technical challenges that have been identified. (Zhou et al., 2024) [117]

This paper presents applications of digital twins within the European Project DigiBUILD, focusing on optimizing energy systems for enhanced efficiency and reduced carbon footprint. It emphasis on data collection, services description and its implementation. It undergoes three case studies, the first is the Heron pilot, that aims to manage a group of buildings and optimally charge electric vehicles to reduce carbon emissions, the second Veolia, where a district heating network optimally manage heat sources in the production plant to reduce gas consumption and emissions and the last Emotion, builds equipped with photovoltaic panels and electric vehicles and implements services for optimal vehicle charging to maximize self-consumption in day-ahead scheduling and also in real time. The challenges and limitations encountered in the deployment of digital twins and emphases on the importance of user interaction in facilitating efficient energy management is done. It is underlined how digital twins might help the EU's sustainability and environmental impact lowering goals as well as help the digitization of the energy sector progress. (Testasecca et al., 2024) [150]

S No.	Author	Year	Objective	Inspiration
1	Sohail Sarwar, et al. (S. Sarwar et al., 2024) [114]	2024	This methodology is founded on a capacity restriction method that is mathematically modelled. It offers a practical solution by preventing outages, even when the number of loads increases.	This technique guarantees that the DC subgrid's maximum power output is reached when the energy storage device is charged utilizing off-peak grid electricity.
2	Wenwen He, et al. (He, Wu, et al., 2024) [115]	2024	Develop a novel worst-case and probabilistic uncertainty sets, along with a new two-stage, four-level robust optimization (RO) model employing a worst-expectation min-max-max-min approach that incorporates incremental carbon trading for MEM.	In comparison to the other prevalent methodologies, the four-level RO mitigates conservatism and optimism to a certain extent.
3	Yuekuan Zhou, et al. (Zhou et al., 2024)[117]	2024	In energy planning and optimization, machine learning (ML) surrogate models for uncertainty analysis, optimization, geometrical and operational	District energy networks use innovative energy converters, energy storage, residual heat recovery from centralized power plants, and on-site

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			parameter design, demand forecasting, and energy distribution show technological feasibility and potential.	renewable energy generation to distribute renewable energy.
4	Tancredi Testasecca, et al. (Testasecca et al., 2024)[150]	2024	Presents the applications of digital twins within the European Project DigiBUILD, focusing on optimizing energy systems for enhanced efficiency and reduced carbon footprint.	Digital twins advances the digitalization of the energy sector, contributing to the European Union's goals for sustainability and reduced environmental impact.

This study examines the utilization of artificial intelligence (AI) to implement and optimize microgrid energy management systems (EMS). It addresses critical components of microgrid design, including cost-effectiveness, system capacity, power generation diversity, and consumer satisfaction. It examines a variety of optimization techniques that are pertinent to EMS, emphasizing their applications, advantages, and obstacles. The study emphasizes the importance of energy storage, demand-side management, and hybrid systems in combating the intermittent nature of renewable energy. The specific applications of AI techniques, such as unsupervised learning (USL), supervised learning (SL), and semi-supervised learning (SSL), are thoroughly explored. The study investigates how primary, secondary, and tertiary hierarchical limitations influence AI. Artificial intelligence approaches such as deep learning for load forecasting and reinforcement learning for optimal control help to improve microgrid dependability and efficiency. The research proposes that combining distributed energy resources (DER) with modern optimization approaches can drastically cut costs while enhancing the operational sustainability of microgrids. This study cited more than 200 research publications. (Bilal et al., 2024)[102]

The impact of artificial intelligence on small-scale electric power systems is investigated. The systems being explored include microgrids, hybrids, freestanding systems, grid-interactive systems, and virtual power plants. We'll discuss how artificial intelligence impacts energy production, storage, grid management, operations, demand response, and energy consumption. AI Acceleration Performance Indicators (AAPIs) for small-scale electric power systems are designed to provide a consistent framework for analyzing and comparing various research. (Shahid et al., 2024)[105]

The most popular optimization and control methods for microgrids fueled by hydrogen are described and examined. The benefits and drawbacks of different strategies are examined. The optimization strategies are categorized based on predictability, deployment viability, and computing complexity. The benefits of deterministic, stochastic, and innovative approaches—including machine learning techniques—are investigated and assessed in this study. With an emphasis on hydrogen consumption, this article examines the advantages and disadvantages of several approaches to modernizing and maintaining hybrid microgrid systems. (F. A. Sarwar et al., 2024)[106]

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It discusses about recent technological developments that have led to the creation and implementation of renewable energy microgrids. First, precise energy flow monitoring and management are made possible by the integration of smart grid technology, which includes sophisticated sensors, automation systems, and real-time data analytics. Peak performance and dependability result from this. Second, especially in remote or off-grid locations, it is now feasible to retain a dependable power source thanks to developments in energy storage technologies. Third, by predicting energy consumption patterns, improving energy distribution, and automating decision-making processes, artificial intelligence (AI) and machine learning have revolutionized microgrid administration and optimization, leading to higher productivity and lower operating costs. By anticipating and reducing possible disruptions like equipment failures and inclement weather, these techniques increase microgrid resilience. Additionally, peer-to-peer energy trading within microgrids is made possible by blockchain technology advancements, which guarantee safe, transparent, and effective transactions. This enables consumers to buy and sell excess energy locally, promoting community involvement and optimizing the use of locally produced renewable energy. Blockchain, AI, machine learning, and smart grid technologies allow communities to take charge of their energy future by boosting microgrid sustainability, dependability, and efficiency, hence enabling a more resilient and sustainable energy environment. (Agupugo et al., 2024)[108]

An artificial intelligence-powered energy management system for electric vehicles that complies with PRISMA guidelines for systematic reviews and meta-analyses is described in this article. The project explores the potential of genetic algorithms, deep learning, and machine learning to enhance the range, efficiency, and performance of electric vehicles. The potential for better energy management, route planning, energy demand estimation, and real-time trip scenario adjustments is demonstrated by the employment of complex control algorithms. The talk delves deeper into how artificial intelligence (AI) can be used to identify issues, schedule maintenance for batteries and electric propulsion systems, and tailor the driving experience according to the driver's preferences and environment. The use of AI in safety and security risk management in energy management systems for electric vehicles is also talked about. (Arévalo et al., 2024)[109]

The residential microgrid EMS in this study is based on non-intrusive load monitoring (NILM) and the Internet of Things (IoT). The EMS is equipped with a battery storage device and a photovoltaic (PV) plant. The construction of a self-sufficient microgrid and an effective load control system are the objectives of this project. To investigate and enhance energy efficiency, we build the microgrid model using the electromagnetic transient tool PSCAD/EMTDC. ANN and PSO work together to regulate demand and segregate burdens. An ANN is employed to increase the accuracy of NILM in the load recognition process, and PSO is used to enhance the ANN algorithm. The ThingSpeak IoT platform receives the NILM output and allows customers to monitor and manage their equipment to reduce energy consumption and, therefore, expenses. (Ramadan et al., 2024)[112]

This study investigates the inadequacies of present control systems in both freestanding and grid-connected microgrids, as well as the use of artificial intelligence approaches in various control schemes, including fuzzy logic, neural networks, and reinforcement learning. The various HESS systems, power converter topologies, and energy management approaches are

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briefly discussed. The review's various faults indicate a promising future for AI in HESS in microgrids. (R. & Kowsalya, 2024)[122]

To identify islanding, a multi-stage adaptive neuro fuzzy inference system (ANFIS) has been developed. This model is trained using a novel hybrid technique that integrates a teaching-learning-based optimizer with Levy flights. Its effectiveness is evaluated through the utilization of IEEE CEC-C06 and supplementary benchmarking functions. The UL1741 standard for islanding prevention confirms the system's detection's precision and speed. (Suman Kumar Gourav et al., 2023)[134]

ALSO-DCGNN is a hybrid system that enhances the power quality and voltage regulation of energy storage devices in a DC Micro Grid (MG) by utilizing the Artificial Lizard Search Optimization Algorithm, Density Clustering, and Graph Neural Network. The DC microgrid inverter (DCMG) system is managed by the ALSO algorithm, while the DCGNN takes other factors into account. By controlling the DC bus voltage and removing harmonic distortion, DCMG improves power quality. The suggested strategy, unlike the present approach, improves sensitivity and efficiency while reducing THD and settling time, as demonstrated by the simulation results. The decrease of THD enhances the efficiency of the power distribution network, mitigates equipment damage, and diminishes interference in communication systems. (Vennila et al., 2024)[136]

In order to optimize MG operations and guarantee the effective use of distributed energy sources, storage systems, networks, and loads, this article looks at the function of control techniques. Demand response, energy storage management, data management, generation-load management, energy management, and MG performance are all enhanced when optimization techniques are combined with artificial intelligence (AI). (Juma et al., 2024)[140]

Several aspects of the use of contemporary AI algorithms for microgrid control are covered in this work. Integrating artificial intelligence into an AC, DC, or hybrid AC/DC microgrid's hierarchical control system increases its ability to learn and adapt to changing operating conditions. (Gutierrez-Escalona et al., 2024)[143]

This research introduces the integration of reinforcement learning (RL) algorithms to autonomously optimize microgrid operations. This application encompasses several situations, including demand-side management, smart grid optimization and the integration of RES. Robust, sustainable and effective autonomous microgrid systems are realized by tackling challenges such as enhancing the complexity of reinforcement learning algorithms to provide resilience in microgrid environments. (Onu et al., 2024)[145]

In order to improve microgrid performance, especially in an islanding mode where voltage and frequency (VaF) variations are a major issue, this research suggests using deep neural network (DNN) predictions. It enables proactive planning and optimization of sustainability, efficiency, and dependability in MG management by precisely forecasting power generation and demand patterns using historical trends and real-time data. By reducing reliance on communication devices, guaranteeing the boundaries of VaF, and enabling accurate power distribution and balanced coordination among dispersed generators, it creates an intelligent distributed control system that maximizes system performance. By integrating DNN-based predictive control,

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which tackles performance issues, MGs' operating efficiency, dependability, and sustainability are optimized. (Hasani et al., 2024)[149]

S No.	Author	Year	Objective	Inspiration
1	Mohd Bilal, et al. (Bilal et al., 2024)[102]	2024	AI integration and optimization in microgrid EMS.	Distributed energy resources (DER) integration and sophisticated optimization techniques enhance microgrid sustainability and yield significant financial gains.
2	Arqum Shahid, et al. (Shahid et al., 2024)[105]	2024	This paper examines artificial intelligence AI technology applications and their range of uses in small-scale electrical power systems.	AI Acceleration Performance Indicators (AAPIs) are being developed for small-scale electric power systems in order to provide a consistent framework for comparing and measuring outcomes.
3	Fahad Ali Sarwar, et al. (F. A. Sarwar et al., 2024) [106]	2024	The benefits of deterministic, stochastic, and cutting-edge approaches including machine learning-based techniques are compared and examined in this study.	With an emphasis on hydrogen, it offers a thorough analysis of the benefits and drawbacks of various strategies for preserving and enhancing hybrid microgrid systems.
4	Chijioke Paul Agupugo, et al. (Agupugo et al., 2024) [108]	2024	Blockchain, artificial intelligence and machine learning, smart grid technologies, and improved energy storage are all driving significant advances in renewable energy microgrids.	These solutions help create a more resilient and sustainable energy environment by enhancing microgrid stability, dependability, and efficiency.
5	Paul Arévalo, Danny Ochoa-Correa et al. (Arévalo et al., 2024)[109]	2024	The impact of recent advancements in AI, such as ML, DL, and GA, on the performance, energy efficiency, and range of electric vehicles has been examined.	AI combined with electric car energy management systems can boost performance, efficiency, and sustainability.
6	Rawda Ramadan, et al. (Ramadan et al., 2024)[112]	2024	PSO and ANN are integrated to perform load disaggregation and choose appliances for demand-side control.	While the PSO method is used to improve the ANN algorithm, the ANN algorithm is used to identify loads. This improves NILM's accuracy. The output is subsequently delivered to clients

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				via the ThingSpeak IoT platform, conserving energy and reducing costs.
7	Shyni R., et al. (R. & Kowsalya, 2024) [122]	2024	This study examines current control strategies, their limitations, and the application of AI approaches in various control schemes, including neural networks, fuzzy logic and reinforcement learning, related to both standalone and grid-connected microgrids.	An analysis of diverse HESS systems, power converter architectures, and energy management strategies.
8	Gaurav Kumar Suman, et al. (Suman Kumar Gourav et al., 2023)[134]	2024	Islands are detected using ANFIS. Levy flights and a teaching-learning optimizer are used to train this model in a new way.	An ANFIS-based detection method that makes use of the suggested LF-TLBO algorithm shows excellent speed and accuracy. Additionally, it can differentiate between real islanding and other similar MG events.
9	C. Vennila, et al. (Vennila et al., 2024) [136]	2024	The hybrid solution also employs Graph Neural Networks and Density Clustering to alter DC bus voltage and reduce total harmonic distortion.	By lowering THD, this technique lessens the possibility of problems including equipment damage, communication system interference, and decreased power distribution network efficiency.
10	Shaibu Ali Juma, et al. (Juma et al., 2024) [140]	2024	MG performance and energy management in control systems are improved by optimization techniques and artificial intelligence (AI).	In addition to giving detailed information on control tactics and designs, the study emphasizes the crucial role of AI and other technologies in improving MG energy management.
11	Javier Gutiérrez-Escalona, et al. (Gutierrez-Escalona et al., 2024) [143]	2024	The most recent studies on using AI-based technology in the hierarchical control structure of direct current (DC), alternating current (AC), and hybrid alternating current/direct current (MG) systems are compiled on this website.	AI's potential to enhance decision-making and learning capabilities in response to dynamic operational scenarios is demonstrated.
12	Peter Onu, et al. (Onu et al., 2024)[145]	2024	Integrates reinforcement learning (RL) algorithms to optimize microgrid operations independently.	The study finds the challenges and predicts the refining of RL approaches, making the way for

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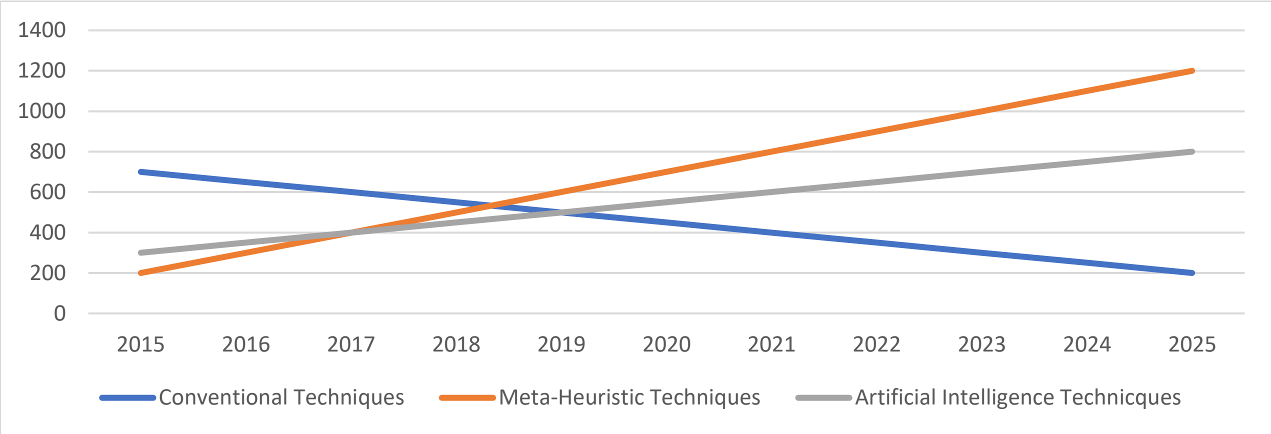
				resilient, efficient and sustainable independent microgrid systems.
13	Afshin Hasani, et al. (Hasani et al., 2024)[149]	2024	Deep neural network (DNN) predictions are used as a control approach to increase MG performance in an islanding mode with large voltage and frequency (VaF) variations.	Because it addresses performance issues and enhances sustainability, reliability, and operational efficiency, this is a major advancement in microgrid administration.



X- Axis represents - Years

Y-Axis represents - No. of inspired optimizations

Figure 3. Application of Optimization in Energy Management

6.CONCLUSION AND FUTURE SCOPE

According to the findings of this research, successful energy management is an essential component of the operation of microgrids. By utilizing the most recent optimization approaches in conjunction with microgrids and renewable energy sources, you have the potential to improve operational dependability, economic effectiveness, and environmental benefits. In areas with limited utility infrastructure or that are remote, microgrids offer a sustainable energy management solution. Currently, artificial intelligence is the primary method used in research, and it is regarded as more significant due to its ability to accomplish global optimums, rapid convergence rates, and precision in calculations. However, the large number of inputs required poses a significant challenge. Consequently, a sophisticated, refined, and precise optimization technique is necessary. Nevertheless, hybrid algorithms are more efficient in solving multi-objective optimization problems and produce more precise results than single algorithms. Thus, thorough research should be given top priority in future studies to create and hybridize efficient artificial intelligence systems.

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