electronics

Review

Integrated Distributed Energy Resources (DER) and Microgrids: Modeling and Optimization of DERs

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Abstract: In the near future, the notion of integrating distributed energy resources (DERs) to build a microgrid will be extremely important. The DERs comprise several technologies, such as diesel engines, micro turbines, fuel cells, photovoltaic, small wind turbines, etc. The coordinated operation and control of DER together with controllable loads and storage devices, such as flywheels, energy capacitors and batteries, are central to the concept of microgrid. Microgrids can operate interconnected to the main distribution grid, or in an islanded mode. This paper reviews the studies on microgrid technologies. The modeling and optimization methodologies of DERs are also presented and discussed in this paper along with system control approaches for DERs and microgrids. The review findings indicate that the use of multimodal indicators that take into consideration the financial, technological, ecological, and social elements of microgrids increased the community's and stakeholders' reaction capability. The microgrid structure under consideration comprises several types of combined heat power devices, boilers, and various types of DERs, including FC units, distributed generators, and MTs. Moreover, compared to grid-connected mode, the microgrid's total operation cost is significantly higher in isolated mode.

Keywords: distributed energy resources; DER; microgrid; renewable energy; photovoltaic

Citation: Twaisan, K.; Barışçı, N. Integrated Distributed Energy Resources (DER) and Microgrids: Modeling and Optimization of DERs. *Electronics* **2022**, *11*, 2816. https://doi.org/10.3390/electronics11182816

Academic Editor: Arturo de la Escalera Hueso

Received: 22 July 2022
Accepted: 29 August 2022
Published: 6 September 2022

1. Introduction

The whole-life cost-optimal combination of the sizes of the prospective DERs and microelectronics is determined via planning optimization. For supply and demand balancing, Microgrids (microgrids) can trade energy and ancillary commodities to the electric grid. In isolated mode, the microgrid is disconnected from the main grid, and the customers get their electricity from the microgrid's DERs. When DERs are integrated into a distribution network, new options for technical, legal, and economic methods to ensure a safe and efficient operation arise. DERs increase distribution network flexibility and enable the distribution system to provide supplementary services to the transmission system. It is important to integrate distributed generating plants with enhanced functionality, as well as deploy measuring and analysis devices on the feeder and demand, in order for isolated microgrids to operate an active distribution system.

The role of distributed generators in power system generation is growing, and microgrids are becoming more prevalent. Low-voltage distribution networks incorporating DER, i.e., configurable loads and storage devices, are found in microgrids. There are numerous levels of decentralization that may be used in microgrid control systems, ranging from a totally decentralized approach to hierarchical control.

Mohamed and Koivo optimized the functioning of a self-contained microgrid over a 24 h period [1]. They conducted an evolution of a model from one cycle to a multi-period optimization model for an interconnected microgrid. The model includes hard inter-temporal limitations, such as distributed generator ramp rate limits, electrochemical storage charge and discharge rates, and maximum charge/discharge capabilities. The proposed model is solved using a genetic algorithm and assessed on a microgrid under various conditions, with the results examined [2]. The frequency management of the power grid has been identified as a major issue, and designing an analytical model for a complicated large-scale power grid is difficult. For enhanced functioning of load frequency control systems, Xu proposed a unique flexible neural networking system that restricted the control using a hybrid energy storage system. A suggested network is examined that does not only transform system state to performance assessment, but also detects the link among control output and long-term control performance, as has been done previously.

The inverter interfaces used in storage technologies, fuel cells and micro-turbines are used in micro-source controller approaches. The rating of semiconductor devices about 2 p.u. limits inverter fault currents. Traditional over-current protection strategies may not be effective in islanded inverter-based microgrids since fault currents are not high enough. Digital relays coupled to breakers are indicated as a solution for power electronics-based microgrid protection coordination [3].

Traditional power systems have a variety of issues, including high emissions, high generating costs, and voltage variations. The microgrid is a system that combines DERs, loads, and storage units to provide power to tiny settlements. The microgrid is not linked to the power grid and operates independently in islanded mode; in grid-connected mode, it aids other producing units in meeting network demand. The retreat building of the territory of renewable energy institute requires additional energy to fulfill total load demand during grid outages. The feasibility of adding a second battery bank and a diesel generator has been investigated. After weighing both possibilities, a small distributed generator with a capacity of 5 kVA (depending on market availability) is incorporated with the current system and deemed an improvement at Territory of Renewable Energy Institutes' Retreat Facility. The use of distributed generators might further improve the system's performance by utilizing more local photovoltaic energy [4]. "Electricity distribution systems include demands and DERs that may be operated in a regulated, coordinated fashion either while linked to the main power network or when islanded," according to the CIGRE's C6.22 Working Group" [5].

The benefits of microgrid sustainability are well understood, but still there are no well-established approaches for assuring and monitoring it (limitations of microgrids are discussed in Section 5). Comprehensive knowledge necessitates a holistic strategy capable of dealing with system-wide characteristics such as uncertainty, evolution, and accumulation. Through solar energy microgrid applications, the Ayllu Solar project intends to promote the sustainable growth of the Chilean regions of Arica and Parinacota (both grid-connected and off-grid). The principles provided in this study compress and enhance the knowledge gained from these initiatives, with the goal of serving as a technique for replicating the Huatacondo microgrid's success in other communities. The "Integrated Energy UNiLAB:DEM" has planned and produced this Special Issue in the hopes of delivering the most up-to-date research in the distributed energy and microgrids field [6]. Given different forms of renewable integration and other obstacles to the legacy system, distributed energy and microgrids have arisen as a viable approach of increasing the quality of energy services. The requirement for flexible demand and energy storage is growing, and the financial case for their adoption is becoming more compelling [6].

Microgrids have an advantage in distant region electrification, since they are less expensive than expensive grid integration, which is often impossible owing to ecological or natural build-up. The goal of this paper is to give an overview of numerous state-of-the-art characteristics that contribute to the development and efficient performance of a futuristic power system based on clean energy sources [7].

Photovoltaic systems, and in many locations, photovoltaic combined with storage, have reached grid parity due to the tremendous decline in the cost of solar photovoltaic and storage. Some utilities have gone even farther to address the issues of integration by encouraging self-generation and eliminating net-metering. Fundamental differences exist between power system and inverter manufacturers designers and operators, hindering the move to renewables even further [8]. Distributed generation is quickly gaining popularity since it provides electricity with less environmental implications, is simple to install, and is extremely efficient and reliable. Distributed generators such as photovoltaic systems, tidal, small hydro turbines, wind power, combined heat and power microturbines, fuel cells, geothermal, biogas, and battery storage facilities, among others, have the potential to support conventional power systems while posing numerous interconnection challenges. The requirements for the microgrid integration of DERs and loads in order to improve power are generating reliability, marketability, and the capacity of scattered microsources. The "IEEE P1547-2003" standard is a benchmark model for linking DERs with traditional power systems [3].

The contemporary notion of microgrid began with the deployment of smart generators based on renewable energy resources and microsources such as solar systems, wind turbines, fuel cells, and batteries with storage facilities [3]. It may work in either islanded or grid-connected mode. When a power quality incident happens, the microgrid can disconnect from the main grid. Because microsources may be controlled autonomously, the microgrid should be peer-to-peer and plug-and-play. The power storage equipment ought to be able to respond quickly to changes in frequency and voltage, as well as exchange huge volumes of actual or reactive power. When it comes to auxiliary voltage and frequency regulation, most microsources have a delayed reaction. The microgrid must be ready for planned islanding, which is a key feature of the microgrid idea that ensures supply continuity during outages. The inverter interfaces used in fuel cells, small wind turbines, and storage systems are used in micro-source controller approaches [3].

When the system islands, the controls include the capacity to manage power flow on feeders and guarantee that each microsource quickly provides its portion of the load. Integrating diverse types of energy sources would also have an influence on the quality of the power supply and produce a slew of control issues. Interconnecting adequately built parallel inverters for seamless transition from grid connected to islanded mode can solve the variation in DER generation and the uncertainty in the usage of renewable energy resources. According to [3], "The solid state power electronic interfaced" relays' quick reaction time can provide effective protection coordination across all relevant protective devices in a microgrid system. A microgrid can be grid linked or islanded, with a rapid semiconductor switch recognized as a static switch connecting it to the main power supply. The rating of semiconductors around 2 p.u. rated current restrictions inverter fault currents. Traditional over-current protection strategies may not be effective in islanded inverter based microgrids since fault currents are not high enough. The safeguarding concept is that both islanded and grid-connected operations should use the same protective measures. A microgrid's stability refers to its capacity to return to regular or steady operation after being disrupted in some way. In contrast, instability refers to a state in which there is a breakdown of synchronism or regular operation. Stability issues must be considered in the steady state, dynamic, and transient conditions for optimal microgrid functionality [3].

The main contributions of this paper could be listed as follows:

1. Indicating and discussing the potential befits and problems of integrating DERs into distribution networks (particularly in isolated microgrids).
2. Laying out some ideas for integrating DER units into the main grid, as well as the next measures that governments should take to integrate them into microgrid operations.
3. Discussing the modeling and optimization methodologies of DERs in detail.
4. Reviewing and investigating the effectiveness of the proposed combined cooling, heating, and power system, which intended to reduce the overall yearly cost of the system while simultaneously lowering the energy cost.
5. Critically reviewing and discussing the studies on microgrid technologies.
6. Evaluating the feasibility of using an actor-critical neural network with a distributed reinforcement learning control method to adjust for power grid frequency regulation.

The rest of the paper is organized as follows. Section 2 gives an overview of the DER modeling which includes defining photovoltaics, energy storage systems, combined cooling and heating, wind turbines, and fuel cells. Section 3 discusses briefly the DER optimization.

Section 4 reviews the literature on the microgrids and also the modeling and optimization of DERs. Section 5 addresses and discusses the limitations of microgrids proposed in studies, and also discusses a numerical study of a community microgrid project with a low-risk, high-return investment that may be owned by the whole community. Section 6 concludes the paper and highlights ongoing research areas.

2. DER Modeling

A. Photovoltaic system

Photovoltaic solar systems turn sunlight into electrical power. Solar photovoltaic has two main advantages. Photovoltaic may be used in extremely tiny quantities. This property allows for a broad variety of deployment options. In 2017, total solar photovoltaic capacity reached approx. 398 GW and produced about 460 TWh, accounting for around 2.0 percent of global electricity output. “Utility-scale projects account for little over 60% of the total photovoltaic capacity deployed, with the remainder being used in dispersed applications (residential, commercial and off-grid)”. “Solar photovoltaic is predicted to lead renewable power capacity development over the next five years, growing by about 580 GW under the Renewables 2018 main scenario” [9].

B. Energy storage systems (ESS)

Energy storage technologies are becoming increasingly important in the planning and implementation of power systems. Power schedulers and policymakers cannot ignore the innovation that storage technologies will offer to future power systems as they continue to evolve [10]. Batteries, flywheels, and ultra-capacitors are examples of energy storage technologies. They are mostly used in islanded mode in microgrids to offer uninterrupted power supply in the meantime of outages.

C. Combined cooling and heating

District combined cooling and heating refers to a system that uses pipelines and networks to supply cooling and heating services to clients near to their homes. District heating and cooling is a type of “central heating and cooling” (CHC) that has been around since the 1930s, with nations such as the United States, Russia, and Germany at the forefront [11]. The purpose of district heating networking systems is to utilize heat sources that could otherwise be squandered to meet customer load via “heat distribution pipes” in the community or at least the neighborhood. While District Cooling is the connecting of numerous cooling sources to consumers via hot or cold water networking systems in order to offer room space cooling. As a result, the combination of district heating, district cooling, and combined power and heat creates a trigeneration system in which high-efficiency cooling, heating, and electrical power are produced with minimal flue gas and carbon dioxide (CO_2) emissions. District heating and cooling has a number of features that make it more appealing to today’s established environment [12].

D. Wind turbines

Wind energy is becoming more popular as a source of power. It turns the wind movement through the earth’s surface into electrical power and is one of the most often utilized renewable energy sources for microgrids, see Figure 1. “Worldwide wind power capacity remained above 50 GW in 2017,” according to the report [12].

E. Fuel cells

Fuel cells transform a fuel’s chemical energy into electricity with a very high efficiency. Moreover, it has the capacity to emit tiny amounts of carbon while maintaining a low temperature. “Their electrical and total efficiency varies depending on the kind of system and system design, ranging from 30.0 percent to 60.0 percent without recovery heat equipment to 80.0–85.0 percent with standard recovery equipment.” [11].

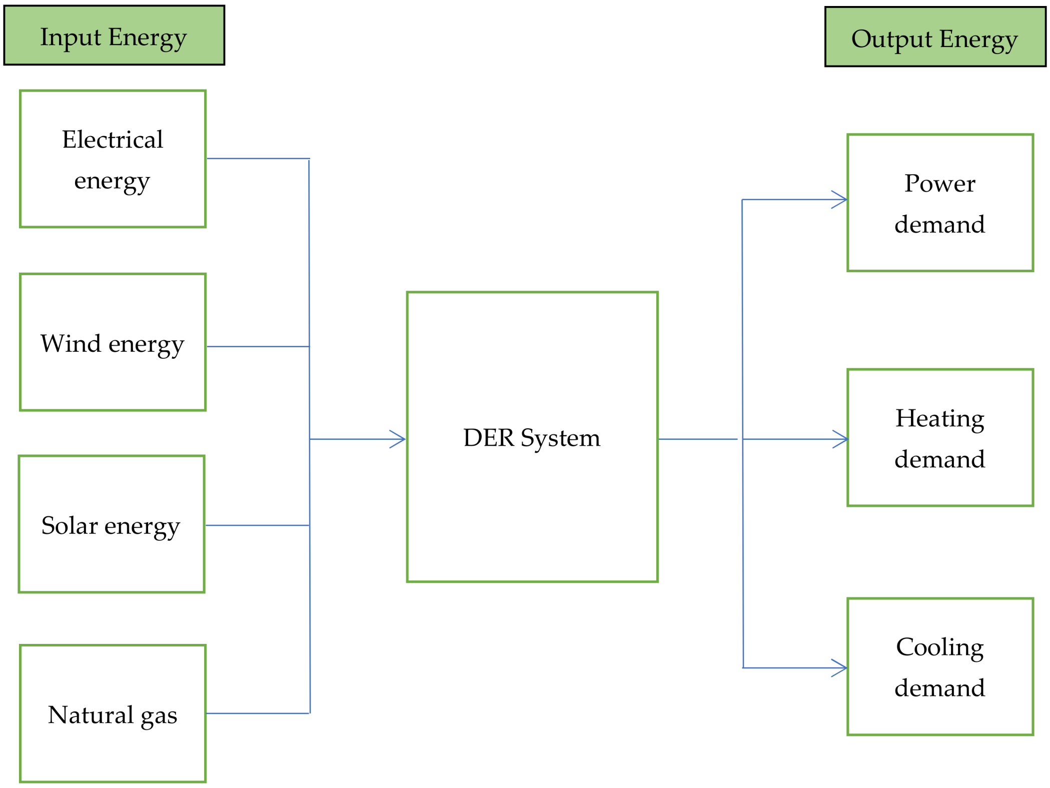

Figure 1. DER Modeling.

3. DER Optimization

The majority of energy management academics are unfamiliar with optimization techniques. Engineering design is made up of multiple objective functions with a high number of decision variables, with the potential solutions being the collection of all r designs categorized by all possible choice variable values. An optimization strategy may be defined as attempting to find the best answer out of all the possibilities [13]. The two types of optimization methodologies are mathematical and heuristics approaches. Figure 2 illustrates this. Heuristic procedures are often simple strategies that produce adequate results quickly but are not always ideal. The simplex approach, the steepest descent, and quasi-Newton methods are examples of optimization methods that utilize mathematical approaches and concepts, which are commonly referred to as deterministic approaches [14].

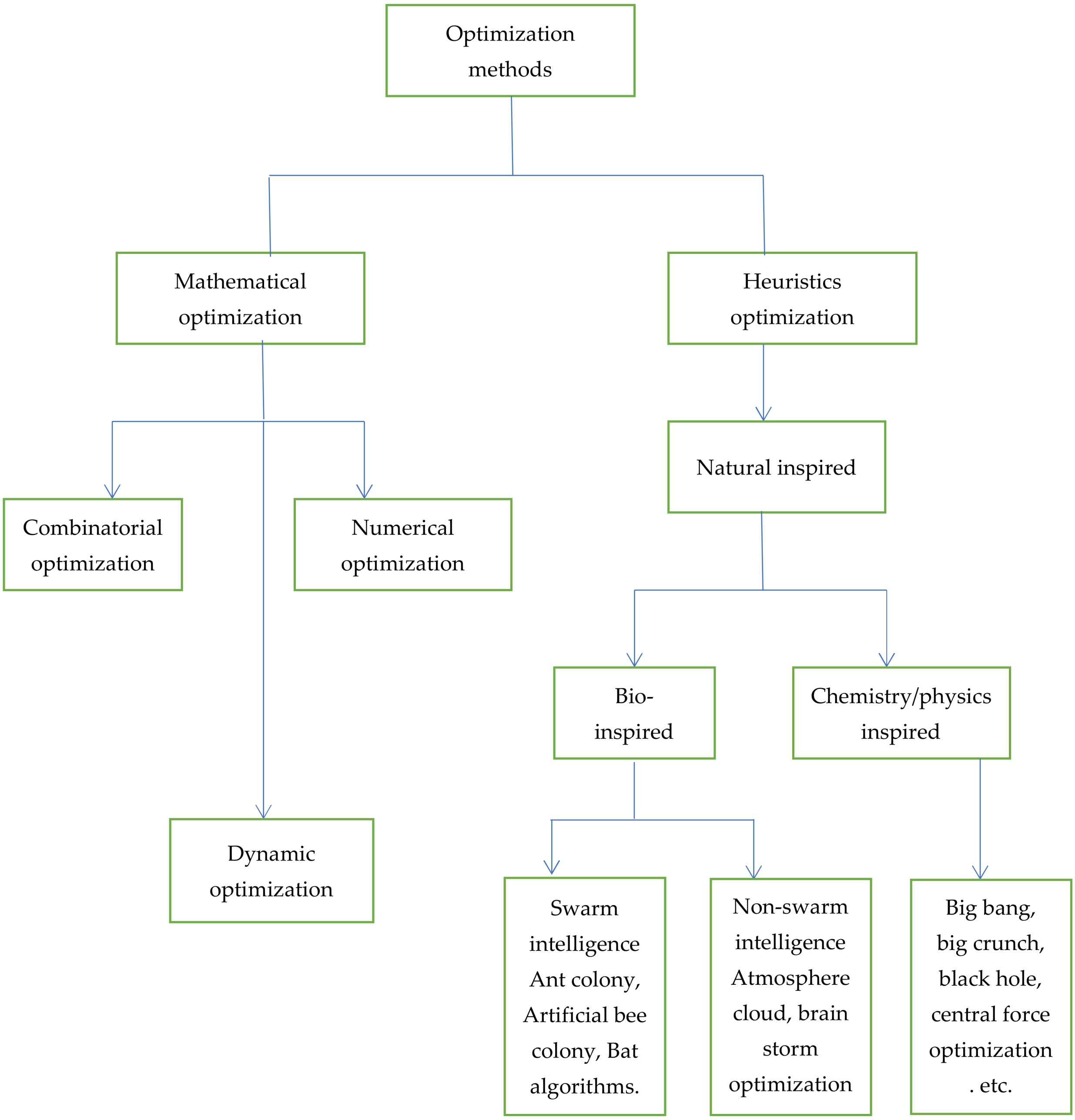

Figure 2. Categories of optimization methods.

4. Literature Review

The modeling and optimization of "Distributed Energy Resources" (DES), which includes "District Heating and Cooling networks", has attracted a lot of interest. Several academics have optimized the design and operation of DER systems for both single- and multi-objective issues in order to minimize yearly costs and carbon emissions into the environment. In modeling, a single objective function is taken into account. In a multi-objective paradigm, more than one objective function is defined. Mixed Integer Linear Programming is a technique for solving complicated mathematical programming problems. "Using different DER technologies including as thermal and electrical generation units, storage systems, and district heating and cooling networks, a hundred buildings at the district network level were analyzed and upgraded for energy savings" in [15]. The model's output may effectively minimize the influence of greenhouse gas emissions in district network buildings, and [16] has a good description of techniques and current research on

DER optimization at the city level, while [17] has a concise overview of approaches and research literature on DER optimization at the rural level.

Various researchers have experimented with single- and multi-objective functions using various technology inputs and have come up with a variety of solutions. By creating the mathematical modeling using a Mixed Integer Linear Programming approach, reference [18] offered a multi-objective optimization by reducing the cost and carbon emission.

The case study included 1 commercial building and 11 residential buildings with a variety of technical inputs such as gas boilers, combined heat and power, water heat storage, photovoltaics, solar thermal collectors, and coupled with a district heating system. "The model has 83,945 variables, 6218 integers, and 108,178 different forms of linear constraints in its many formulations. In comparison to the benchmark, the results suggest that the model might effectively lower emissions by 23%". The authors of [19] used deterministic "Mixed Integer Linear Programming" to create a mathematical model that included the economic and environmental advantages. Under diverse design and operational restrictions, the model was constructed as a multi-objective logistic issue to improve the DER system by reducing total yearly cost and carbon dioxide emissions. The case study consisted of four buildings: "two housing and 2 office buildings connected by a district power, heating, and cooling network. PGUs, boilers, heat recovery systems, heat exchangers, heat and cold storages, and absorption and compression chillers are among the different technology DER inputs" [19]. They picked a Reference Energy System to utilize as a baseline for their own system. The model was able to select the suitable system operating strategy, and it was also determined that the model outperforms the "Reference Energy System" by saving 16 percent of the total cost and 45 percent of CO_2 emissions. In [20], Jayasekara et al. proposed optimizing a combined cooling, heating, and power system to reduce the overall yearly cost of the system while simultaneously lowering the energy cost.

The contributions of [21] are based on DER assessment planning that was multi-objective and multi-criteria. The data were collected from a fancy hotel in Sri Lanka and a fancy hotel in Australia over the course of a year. According to the findings of another research, the proposed strategy was able to lower overall yearly costs by 13.0% and 7.0% in Sri Lanka and Australia, respectively [22]. The primary goal was to reduce operational costs by delivering energy at a low cost. The literature on capacity planning for sustainable power systems may be divided into two categories: accurate mathematical optimization methods and artificial intelligence (AI) methodologies. Although defining the economical microgrid energy scheduling issue in such a way that accurate mathematical solution algorithms can solve it lessens the computing effort, it significantly raises the probability of sub-optimality [23]. Number of parameters should not be the major consideration while optimizing the best microgrid asset allocation because it is an off-line, one-time activity. In this light, new research suggests that AI-based meta-heuristic optimization algorithms can be used instead of traditional optimization approaches. Meta-heuristics can solve the NP-hard issue in polynomial time while addressing model-inherent nonlinearities and non-convexities effectively. The article swarm optimization and the genetic algorithm are two of the most extensively utilized algorithms in the literature. In the literature and industry, there are several microgrid design optimization and long-term investment management software programs. The techniques to problem solving utilized in these tools may be divided into two categories. The 1st class solves the optimal design issue using a straightforward full-factorial technique.

A more algorithmically sophisticated linearized technique to equipment capacity management, such as mixed-integer linear programming, is used by the second class [23–28]. "The crisis of an microgrid has been studied from a variety of perspectives, including problem modeling, single- and multi-objective functions, the effects of combined heat power systems, considered uncertainties and modeling techniques, robustness to operational scheduling, optimization approaches used to solve the model, demand response (DR) programs, and so on" [29]. A stochastic cost-emissions based paradigm for optimum joint power and buffer planning of a sustainable microgrid was given in [29], with the goal of enhancing microgrid social welfare while reducing emissions of the environment. "In the presence of electric vehicles, a day-ahead framework has been established to handle distribution feeder reconfiguration as well as optimal generation scheduling in the microgrid while addressing uncertainties" [29]. By recovering heat lost during the generation of electrical energy, combined heat power units help to improve the efficiency of the operating system. combined heat and power economic dispatch is a tough non-convex optimization problem [30] proposes a stochastic-robust optimization model for combined cooling, heating, and power-based microgrid, which takes into account multi-energy operation and power exchange with power market. DERs are frequently managed to run at a constant or even unity power factor in most prior microgrid scheduling systems.

An optimization framework for the power and heat economic dispatch of microgrids has been created, taking into account the benefits of the heat buffer tank and the energy storage system [31]. "To manage active-reactive power dispatch, both operation modes for a grid-connected microgrid have been established" [31]. In both grid-connected and isolated modes, the bulk of the research in the literature has not addressed a unified and combined active-reactive and heat powers scheduling framework in the microgrids. Reference [32] presents a complete model for DER and combined-heat-power-based microgrids to identify the best economic dispatch of active and reactive electricity as well as frictional heating. Load shedding is used in the microgrid optimum operating in the isolated mode, and it is based on the value of lost load principle [32].

Small-scale generation's integration into the distribution network alters the traditional operating model, resulting in economic and technological benefits. In terms of economics, connecting these techniques to the distribution system minimizes network congestion-related distribution costs, as well as power losses and financial factors [33,34]. The development in distributed generators, storage systems, and demand as an active agent with market involvement has resulted in multidirectional flows in active distribution networks. Demand side management refers to the planning, execution, and oversight of operations intended to cause changes in consumption patterns in order to improve energy efficiency and operate the electrical power systems [35–37]. According to [38], "demand response is the pooling of affects throughout the whole distribution network, allowing the system to be more flexible at a lower cost. Incorporating active demand into the system's functioning can help to reduce the fluctuation and uncertainty associated with renewable energy sources" [38]. If we are planning to create an adaptive and dependable functioning of microgrids with the potential to run by local production units, including energy storage systems is advised. When used as separated discrete units produced, the primary function of energy storage systems is to keep it balanced between demand and supply. These systems might provide auxiliary services such as frequency management and reactive control (through inverters and converters), allowing restoration activities to be completed faster. The capacity of the lines increases as demand varies, which is one of the benefits of the microgrid operation. "When distributed generators are linked to a microgrid, they have a major impact on power quality, stability, and voltage profiles, making them a geographically localized voltage control. A flexible and dependable operation, which enables the distribution system to isolate faults and maintain acceptable standards of protection, dependability, and quality in the electrical supply for connected consumers, is one of the challenges of DER integration" [39,40].

The performance of a number of functions such as power generation analysis, monitoring, and forecasting is characterized as microgrid energy management system (EMS). Researchers divided microgrid EMS techniques into five categories, each of which employed a different solution strategy to arrive at an ideal solution for microgrid functioning. In each of the following sub-categories, a comprehensive critical analysis of these tactics was offered, along with a description of the solution strategy used. Tenfen and Finardi offer an ideal power management method in [41] with the goal of lowering microgrid's operational costs. This model demonstrated several of the benefits of DR software, such as load factor optimization, coping with renewable energy resources' intermittent and fluctuating impacts, and lowering peak consumption, among others. Alavi et al. in [42] designed an ideal EMS model to enhance the microgrid, with the goal of lowering emissions, operating and maintenance expenses, and microgrid dependability costs. Ho. P.H.A and Cao. V.K developed a real-time optimum energy management method simulation for the final microgrid architecture and an optimum energy management method employing intelligent optimization approaches to optimally execute the hybrid heat and power insulation microgrid in [43]. The results revealed that the multi-population coevolution-based multi-objective particle swarm optimization algorithm's performance improves as the simulation period and Pareto interface thickness increase. Santis et al. in [44] present an enhanced microgrid model that incorporates a fuzzy logic-based EMS and employs a hierarchical evolutionary algorithm.

A district cooling microgrid structure has been developed using an input-output nonlinear neural network. "Transys", "Matlab", "Genopt", and "Trnopt" software tools were used to model the system. It was compared to the centralized fuzzy logic-based EMS technique in terms of economic gains. In contrast to recurrent neural networks, a trustworthy neural network technique for representing a nonlinear constant relationship was used to construct a robust control scheme. Julio. C et al. offer a system in [45] that maintains a balance between various energy sources, such as wind, solar, hydro, and geothermal energy, on the one hand, and storage units, such as flywheels, fuel cells, and batteries, on the other. With a power of 10 kW, the working method was based on the suggested PMS system and then numerically assessed using SIMULINK-MATLAB. The salp swarm optimization method for the adaptive tuning of an ideal controller is based on artificial intelligence. During load shift situations, the proposed grid-connected microgrid controller is meant to achieve a pre-determined active and reactive energy exchange chances among the utility grid and the distributed generator. The simulation was run, and the results reveal the level of growth that resulted from microgrid's reduced reliance on the main network and increased usage of renewable energy. To verify the superiority of the proposed controller, the performance of the algorithm was compared to that of the prior grasshopper optimization algorithm for the same operating conditions and system configuration. "The results showed that the proposed microgrid controller outperforms its competitor in terms of power quality and transient response" [46] EMS is based on techniques to resilient and stochastic programming. A number of works that are linked to this one will be highlighted.

Ghasemi suggested "an agricultural community connected to the microgrid network" in [46]. The suggested solution establishes a coordinating framework for lowering the costs of both the water supply and the pumped storage unit, as well as energy trading with the primary grid.

Farzin et al., on the other hand, advocated for a randomized EMS to ensure optimal microgrid functioning during unexpected reflux episodes [47]. The purpose of their strategy is to lower microgrid's predicted operating costs, which include load separation costs, small turbine operation costs, revenue possibilities, wind and battery power costs, and risk factors related with the target function's value. The suggested system also included sensitivity analysis, which looked at risk variables, downtime impacts, and battery operation. He and others did so in [48], it introduces a strong two-stage optimization based on the grid-connected microgrid EMS model, which executes unit commitment one day early in the first stage and energy trading and actual financial dispatch in the second. In comparison to the greedy algorithm, the proven Lyapunov optimization approach was applied in the suggested strategy.

A number of works that are linked to this one will be highlighted. Introducing a non-linear model predictive control technique to the microgrid EMS model is island based to assure its stable operation by Minchala-Avila et al. [49]. The load separation strategy and state of charge battery control process stabilized the microgrid system. The payload was specified using a synthetic neural network, and the power output of the conjugate gradient was projected using both an adjustable fuzzy neural inference system and projections of demand based on load demand. When putting inference methods to the test, the proposed strategy performed better [50]. Increasing the efficiency of the networked microgrid network's EMS operation is achieved by presenting the following coordinated two-step approach: the first stage pertains to the microgrid's regular transmission operation in the environment, while the second stage is a one-stage tuning. This suggested technique addresses any real-time load generation imbalances caused by the unpredictability of renewable energy resource power output on the one side and load need on the other. Proudan et al. propose a fault-tolerant EMS for controlling the linked microgrid network [51]. Market pricing, need, load and generator mistakes, and uncertainty in renewable energy resources were all considered in the suggested strategy.

Moreover, the battery expense is incorporated in the aging factor control goal function. Finally, by exposing the fault-tolerance approach as a constraint file, the availability of appropriate funding from the energy storage system was secured to fulfill the load requirement during generator faults. The central controller shifts the microgrid system to stand-alone mode from grid-connected mode in response to any big event in the main grid. Because voltage and frequency variations become more noticeable at that time, each DER's micro-source controller should adjust its amplitude and current to preserve microgrid stability [52]. Local micro-sources controller and central controller are used to regulate and coordinate microgrid management and operation in both modes [52]. The microgrid is controlled by the central controller using the most appropriate control techniques, such as decentralized and hierarchical control, expert system control, and real-time optimization. The system to be improved is expressed as a linear programming or nonlinear programming optimization issue in an optimization method [11]. The goal function and constraints in linear programming algorithms are both linear coefficients, but the objective functions in nonlinear programming algorithms are nonlinear formulas and the constraints are regular formulas. Nonlinear programming may also be used to analyze separable or convex networks [53–55].

The use of expert system control mitigates the problem of real-time optimization control, namely, that it places too much computing strain on the central controller. The AI technology (e.g., "Fuzzy logic") that simulates human thinking can be employed for central controller design in this control method. Li et al. presented a novel grid-interfacing power quality compensator for "three-phase three-wire microgrid applications" in their research [56]. Krishna et al. used the Genetic Algorithm in MATLAB to construct a statistical tool for declaring the sizes of DERs for an "autonomous microgrid islanded mode" functioning of a radial distributor. "The modeling and control challenges of internal combustion engine driven winding field synchronous generators in microgrids were investigated by the US Department of Energy" [57,58]. They came to the conclusion that while a non-inverter may be employed as a distribution generator, the internal conventional generator is more effective [59]. Serban suggested a control technique that can operate in off-grid, genset-connected, and grid-connected modes of operation [60]. Employing back-to-back converters, Majumder et al. suggested a control technique to support actual and reactive power exchange across the microgrid and utility. They used distributed power generation modules to incorporate a pseudo-droop control mechanism into a microgrid. Between the hybrid converter and photovoltaic inverter components, no extra hardware or communication cable connections are required.

Ahn et al. suggested a "technique for changing the feeder flow control-mode distributed generations' droop constant to guarantee proper power sharing across distributed generations" [61]. Yuen and Yuen developed an uncoordinated and coordinated control strategy for supplying basic frequency regulation reserves from several microgrids in their study [62]. Zhong et al. detailed the mechanics, construction, and functioning of synchronverters, which are inverters that imitate synchronous generators. They came to the conclusion that synchronverters are simple to use in both microgrid operation modes, and hence provide an optimal control solution for microgrids [63]. The suggested method accomplishes power source planning and management in three phases, according to [64].

The initial step is to plan each microgrid individually in order to satisfy its particular load requirement. Determine the best prospective offers to export electricity to the distribution network and participate in a full sale energy market in the second stage.

Ross et al. developed a novel online intelligent technique for optimal tuning of the most popular current PI-based frequency controllers in AC microgrids [65,66]. They discovered that using updated models of optimization algorithms can lead to improved results. Guerrero et al. presented a broad strategy to standardization in [67]. They presented hierarchical control with three levels of control. The droop approach is used at the first control level. The second control level permits the deviations produced by the "first control level" to be restored. The output current between the microgrid and the outside power distribution system is managed at the third control level. Wu et al. established a method for regulating inverters locally [68]. The very first characterization is that it allows the microgrid to adjust online power generation to loads, minimizing fuel consuming and thus the cost of CO_2 emissions; the 2nd characterization is that it allows the microgrid to adjust online electrical generation to loads, minimizing fuel consuming and thus the costs of CO_2 emissions. The second advantage is that it is simple to integrate into a "low-cost controller" or "micro-source controller" and that it can operate online [69].

Gu et al. presented a cooperative frequency control strategy including a microgrid central controller and a micro-source controller to achieve a smooth transition from grid-connected to islanded mode [70]. A local energy management technique for hybrid photovoltaic and storage tanks in microgrids has been proposed in [71]. Each source's power reference and control signals are determined by this technique. The findings show that the suggested technique produces output power that is quite smooth. In [72], Morais et al. proposed using two fuel switching load management algorithms in plug-in hybrid cars to increase energy management flexibility. The implications of thermal limitations on the design of distributed power modules were explored in [73], and then optimum DER unit planning was carried out. Sustainable energy for everyone (SE4All) solutions have been used in minigrids [74], where renewable energy-based distributed generating resources have a high penetration. According to the findings, power system policymakers should pay greater attention to remain sustainable in order to alleviate the consequences of global warming and climate change.

Sanjari et al. presented a new optimum control approach combining a storage system and a load-shedding mechanism to preserve frequency response in the microgrid [75]. They employed (1) colonial competitive algorithms for cooperatively developing micro-source controllers in order to keep the microgrid stable, and (2) the Levenberg– Marquardt algorithm for producing controlling signals for each controller in order to keep the frequency and voltage in a specified range.

Dou et al. suggested a smart control approach for operating a smart-microgrid based on hierarchical hybrid control [76]. For a variety of reasons, microgrids and DER are upending the century-old industrial status quo. The qualities of electricity as a resource make it particularly challenging to build effective markets. The economic feasibility of integrated smaller-scale energy systems necessitates extensive operational optimization. Because they are generally building-scale systems, challenges including changing occupancy, weather sensitivity, and non-dispatchability of several sustainable energy resources come into play. The management of the future distribution network will be a more fluid and difficult technical endeavor, and the material in [77] examines one essential part of this task, reactive power provision. Two methods for provisioning in a grid-connected microgrid are considered: switching capacitors on the grid side and photovoltaic inverters on the microgrid side, with a genetic algorithm employed to discover the best solution. "The fluctuation of sustainable generation and loads presents a well-known control challenge for small systems, and [78] investigates the functioning of the resulting household batteries" [78]. Under a regular tariff, the authors estimate the advantages of central centralized control of these batteries. The impact of various low-carbon technology acceptance behaviors by a variety of socioeconomically different neighborhoods is examined in [79].

A revolutionary coordinated frequency control (CF C) technique is described in [80]. This design depicts the rapid response of photovoltaic systems, battery-based systems, and thermostatically regulated loads (TCLs), as well as the delayed response of the diesel generating system. The goal of this system is to manage the frequency by using the device's quick response in a transient state and then returning to normal operating conditions in a steady state. During normal operation, the photovoltaic and energy storage subsystems supplied power by adjusting the demand on the diesel system without the use of an interlink device. As a result, following over-frequency regulation, the photovoltaic system is gradually flipped back to the constrained photovoltaic power period to MPPT.

Based on the aforementioned concerns, the microgrid is designed to meet the aims of continuous supply and cost-effectiveness. In the microgrid, the scheduling process is carried out by an energy management approach, which may work at frequencies lower than power and influence managerial level. As a result, the microgrid system has a significantly lower effect on the attainment of stability and durability. Management and control techniques may have an impact on the current provisions concerning frequency, voltage, current restrictions, and power quality. As a result, [81] proposes an adaptive online microgrid EMS. This system ensures correct module integration and communications as well as the regulated interface. In microgrid systems, it is responsible for planning, scheduling, data collecting, and processing. The technology adapts to the fluctuation of the sustainable generator. For islanded or grid-connected activities, the scheduling procedure is based on economic management. In order to conduct minimal prediction error in the system, the processing module is based on the forecasting module's results. This system must create connecting commands for DER controllers in order to optimize the overall system, which includes not only much improved microgrid efficiency, but also technical, economical, ecological, and environmental regulatory constraints. Thus, this system has the potential to operate in several modes in microgrid and has overcome the operating costs.

The microgrids' operating performance, control methods, and difficulties are discussed in [82]. The power command and management techniques are the most important factors in the functioning of microgrids. Thus, this work presents the control techniques and power management tactics of different kinds of microgrids under different operational conditions [82].

According to [83], "the power balance at the district cooling link is maintained in district cooling microgrid by controlling the district cooling link voltage. However, the AC microgrid control also comprises keeping voltage and frequency within limitations so that synchronization with the grid is maintained. The district cooling microgrid was chosen for its higher effectiveness, stability, simpler design, and minimal power losses" [84].

A mixed-integer linear programming model was proposed in [85] for evaluating investments in substations, circuits, capacitor banks, non-renewable distributed generation units, and renewable energy and EV charging stations (EVCS). In the same way, a mixed-integer linear programming model in [86] finds optimal expenditures in substations, networks, rechargeable batteries, renewable distributed generation units, energy storage systems, and EVCSs. The models developed in [85] and [86] featured stochastic behavior connected to conventional demand; to cope with those unknown ties, resilient optimization and probabilistic coding were used. Unlike [86], the suggested model in [85] did not account for uncertainty in electric vehicle demand. The authors of [87] created a multi-objective distribution system expansion planning (DSEP) model with high wind power penetration, which includes EVCS planning.

Predicting the electric vehicle charging demand pattern is a difficult endeavor due to the small number of real-world examples documented, uncertainty in driver behavior, the amount of electric vehicle penetration, and the power needed by these cars, among other factors [88]. System operators, on the other hand, are concerned with anticipating electric vehicle charging usage in order to estimate the consequences and demands for modernizing the EDS infrastructure [88]. As a result, a method to describe the uncertainty in electric vehicle charging demand is provided here to quantify it. The approach used to predict electric vehicle demand described here is based on [85]. In contrast to [85], which uses data from internal combustion engine travel patterns [89], the electric vehicle infrastructure projection tool (EVI-Pro) Lite [90] was utilized to establish the electric vehicles arrival timings in this proposal. Furthermore, just one type of electric vehicle charger (slow charger (3.3 kW)) was studied in [85]. In this concept, however, the chargers employed at the stations have power ratings of 7 kW (slow charger), 50 kW (rapid charging), and 150 kW. (super-fast charger).

The resulting electric vehicle demand profiles are connected to the other unknown factors (conventional demand, solar irradiation, and wind speed). To illustrate the uncertainties, a set of yearly scenarios is generated by combining historical demand data (Brazil) [91], solar insolation data [92], wind speed data [92], and the electric vehicle charging requirement supplied by the technique described in Section 2. Given the large number of possible situations, the k-means situation reducing approach is used to achieve computational tractability. The k-means clustering approach is commonly used to simulate uncertainty in medium and long-term planning [93]. This type of clustering algorithm preserves correlation among unclear info.

“For DSEP problem, a mixed-integer linear programming model has been presented in [94]. Uncertainties in conventional demand, electric vehicle demand, and renewable generation, as well as investments in distributed generation units and energy storage systems, were all taken into account”.

A two-stage energy management model for the sustainable wind-PV-hydrogen-storage microgrid based on receding horizon optimization was proposed in [95], and the role of energy storage has also been explored. This model is conducted for the purpose of tackling the uncertainties and randomness of renewable energies and loads, as well as to minimize the operation cost. “The day-ahead optimization model is used to trace the day-ahead schemes and reduce the variances between the intra-day and day-ahead operating strategies” [95].

González et al. [96] proposed an innovative multi-layered architecture to deploy heterogeneous automation and monitoring systems for microgrids. This research proposes and validates a unique multi-layered architecture. This design, which is divided into six functional levels, is dedicated to arranging the heterogeneous parts for energy automation and monitoring in microgrids. Interoperability is handled effectively throughout the Modbus TCP network, and data transfer is completed successfully.

According to the authors, this variability necessitates various infrastructure upgrading requirements. The revolutionary Brooklyn Microgrid demonstration’s market design strategy, which is developing a communal energy market utilizing blockchain technology, is explained in [97]. This will undoubtedly be one of the first implementations of a strategy that is generally predicted to transform local energy markets. While the threat of DER to electricity quality is frequently highlighted, solutions for improving outcomes are more difficult to come by. The authors of [98] seek a novel method that might enable the distribution network controller to better govern the network by marshaling scattered assets. In [99], Ceseña EA et al. address the complicated subject of how a microgrid operating inside a reconfigurable energy framework could co-optimize various service offerings. To provide services, the microgrid can draw on the different qualities of its assets. Together, these studies provide a strong foundation for tackling the arduous task of reworking our socioeconomic system to meet local energy needs in a low-carbon society. Each study focuses on a unique facet of the problem and proposes a novel solution.

5. Discussion

5.1. Addressing the Limitations of Microgrids

“Nonlinear mixed-integer programming” with severe inter-temporal constraints is the optimization issue. Mathematical approaches are ineffective in solving this problem since they are model-based, and derivation requires an accurate model of the system. Furthermore, they begin at a single location, and the likelihood of capturing in a local optimum is significant for these approaches. In contrast to mathematical approaches, genetic algorithm (GA) is an inhabitant, data-based, and free-derivative method that uses genetic operators to reduce the likelihood of trapping in a local optimum. As a result, GA is employed in this study. The outputs of base load power generators, storage charge and discharge capacity, and load curtailment values are all included on each chromosome. A backward/forward power flow [100] is conducted for each chromosome based on the aforementioned parameters to calculate the power exchange between the microgrid and the main grid, as well as the microgrid power losses. The sufficiency and stable security limitations are evaluated in power flow calculations, it should be noted. The optimal solution is generated after all other constraints have been checked, and a cost term is applied when the restrictions are broken. If the goal function does not improve for a specific amount of generations, the algorithm will cease. It is set to 50 in this study using a set-and-test method. The efficiency of the provided concept is demonstrated by putting it to the test on a microgrid and assessing the outcomes [101].

According to [102], DERs can be defined as "devices that run in parallel with the utility at all times and provide sensitive loads that may be turned off when necessary". Photovoltaic systems, wind energy systems, fuel cells, combined-heat-power-based micro-turbines, and super conducting magnetic energy storages are examples of DERs described in an integrated approach to DER adoption in the distribution network's immediate vicinity. The authors aimed to develop an integrated, iterative, and comprehensive strategy. It was a first step toward creating an implementation strategy for communities centered around a feeder that might serve as a microgrid. The geometry of this integration is determined by the individual connections of each DER parallel to the grid system in semi-autonomous clusters of small, scattered-type sources associated with loads, which is referred energy as a microgrid. Reference [103] discusses the advantages of adding dispersed resources into an industrial site that is planned as a plant with a large number of induction machines. In islanded operation, the efficacy of the local voltage regulator during load sharing and load change features has been proven. Barkeley Lab has created an economic model of DER deployment to identify the ideal number and kind of modest on-site generation utilizing DERs. Microgrids can have a proper business consumer, such as an office building, restaurant, retail mall, or grocery store, according to [104].

The Distributed Energy Resources Customer Adoption Model is a sort of model that can anticipate DER uptake by commercial clients. Early results demonstrate that, in all cases studied, ordinary business clients can embrace DER: [105] appears to be the first time a tiny gas turbine producing system feeding a microgrid is disclosed; [106] examines a DER business case at the "San Diego biotechnology supply company BD Biosciences Pharmingen", which evaluates DERs for a facility with a base load of 200–300 kW. The site is simulated as a DER-CAM, which is comparable to a model created at "Berkeley Lab" to find the most cost-effective DER system for a particular location. In the context of the power–electronic interface and control techniques for quick management of voltage and frequency magnitude, the steady state and transient functioning of a microgrid is achievable among distributed microsources. Based on the quality of microgrid power and the power transferred across the microgrid and utility grid, a grid connecting a voltage stability compensator for three phases and three wire microgrid applications is conceivable. To get the most out of RESs, researchers are attempting to establish a link between the restricted supply of electricity from RESs and demand-side usage. The authors in [107] recommend, for example, the implementation of a pre-paid pump station with certain control capabilities that may respond to customer demand. The total energy distributed is related to the monthly supply of a restricted amount of power to distribute electricity equitably. In [108], the concept of running an inverter that acts as a synchronous generator is created and offered. It may be regulated using synchronverters in the same way that classic synchronous generators are. A control approach is provided for balancing microgrid power by regulating the fixed value of microgrid voltage level at the transformer side as a function of the link voltage. For the scheduling of an energy storage system deployed in a wind-diesel isolated power system, a knowledge-based expert system is presented [3]. When the utility grid undergoes anomalous conditions, microgrid protection problems must be addressed. Consortium for Electric Reliability Technology Solutions (CERTS) recommended the essential measures and considerations for operating a microgrid in an abnormal state owing to a failure. During a fault, the protection coordinator would quickly isolate feeder faults and islands the microgrids from one another. Protective relays must also be strategically located throughout the grid, with a control system to trigger those relays in time. The voltage/power consistency within the stated parameters of microgrid operation is designed and deployed in a stable condition by dispersed-type distributed generators.

In stability studies, the influence of preventive compensators and factors such as the generator set's actual inertia should be taken into account. The authors of [109] examine a microgrid system with a continuous power demand and find that, based on the negative resistance characteristics, constant power loads render the system unstable. The authors of [110] investigate the stability of an automated microgrid, a topic that is becoming increasingly popular as distributed generation becomes more integrated into the power system. Droop features for grids with dominating resistive and resistant lines, as well as the influence of reverse droop features on small-signal stability and line segments with various X/R ratios, are investigated. In [3], an adaptive feed forward compensation approach for "modifying the dynamic coupling between a distributed resource unit and the host microgrid in order to improve the system's stability" was described.

Eto et al.'s goal [111] was to lay the groundwork for a multi-year research effort that would make it easier to integrate large-scale DERs into current distribution infrastructure. Marnay and Davis emphasized the necessity of DER integration in meeting future power needs in developed nations [112]. Davis presented a tiny gas turbine producing system for a microgrid for the very first time [113]. It has a high cost of installation, connections, and security. Its investment costs are also expensive, and its coherence is low. The CERTS has been continuously examining and reviewing test facilities since 1999, when the initial actions on DER integration began. The microgrid was characterized by Kueck et al. as a combination of electrical demands and non-conventional/sustainable energy sources, where some of them create overheating that may be used for home and industrial heating [114].

5.2. Numerical Study

The proposed community microgrid project is a low-risk, high-return investment that may be owned by the whole community. The investment proposal's levelized cost of electricity, modified internal rate of return, and distribution to paid-in capital were found to be USD 0.02/kWh, 5.40 percent, and 1.42 percent, respectively. The metrics for the most cost-effective conceptual microgrid setup were evaluated in terms of those for a control case scenario. The existing electrical supply system at the site is represented in the base case scenario. The data models used in the application use cases are adaptable, allowing for a wide range of data handling scenarios. They include the bare minimum of information essential to provide DERs with an appropriate degree of control. When a product is reserved or activated, the majority of this information is reused. The weather and pricing forecasts and measurements are based on a current data model; thus, they are not included in this report. The majority of countries have concentrated on expanding power coverage without considering yet if the improvement efforts is long-term and medium-term sustainable. It is crucial to remember that in Colombia, like in many other parts of the globe, the electricity of these remote places is mostly accomplished using diesel generators and a few modest hydropower projects. The high reliance on small-scale diesel production units raises fuel prices significantly, particularly for petroleum countries. It also undermines the viability of enterprises in these areas that are involved in the electrical supply chain. When isolated microgrids run, the balance between the electricity produced in distributed generation facilities and the energy required by consumers must be appropriately adjusted. The use of DERs in an independent microgrid has the potential to provide benefits such as technical durability in the medium and long run. In the long run, the introduction of voltage and frequency regulation as auxiliary services would allow for the decrease in energy not provided due to inadvertent disconnections, allowing for the reduction in energy not delivered. A technological infrastructure, comprising a processing and automation system, automated safeguards, and aspects of active distribution systems linked with DERs, must be in place from a technical standpoint. The NIZ's pilot projects might be regarded knowledge sources for the design of advanced grid technology in Colombia in particular. The assessment approach described in the strategy for the installation of smart grids might be used to evaluate these activities. The goal is to make the distribution system more responsive and to provide ancillary services to the transmission system, as well as to maximize the benefits of new technology integration.

The input signal of the deviation in transfer functions rises continually with respect to time, indicating that the system is unstable. Under the application of modest load disturbances at separate buses, the hierarchical controllers are extremely resilient at smoothing out oscillations and settling fast at a new operating point. The hierarchical controller, unlike the decentralized controller, can enhance the reliability of microgrids with static and static loads. Huatacondo and its residents have gone through all of the steps outlined in this study for a sociotechnical system's energy transition. The population and stakeholders were included early on in order to collaboratively identify the aspects of the intervention. After this point, the microgrid is established, and electric energy usage patterns begin to shift. This shows that the intervention has had an impact on the co-evolution of institutions, equipment, industrial networking systems, and activities in the area. Microgrids are systems that, over time, reshape societies and their habits in the same way as microgrid applications affect societies [115,116].

A re-composition of territory, social meaning, and political structure of power generation, delivery, and consuming occurs as a result of this reconfiguration in renewable technology and economics. It is necessary to monitor and enhance microgrid resilience. Engaging both in a comprehensive and dynamic process of education, information exchange, and collective learning community and technical personnel is a focus. What constitutes a 'resilient' microgrid or a 'sustainable' energy transition, as well as the underlying norms and assumptions, is highly dependent on the region and people to which it is implemented. Practices and indications that worked for Huatacondo might not be appropriate for other microgrids. The applicability of our approach to other situations (such as the "Ayllu Solar project") would necessitate a thorough and place-based co-construction process.

6. Conclusions and Future Works

According to the literature reviewed in this paper, the proposed paradigm for co-optimizing the construction and planning of microgrids may be used in larger-scale community initiatives. In-depth energy management assessments for the min and max net system load days have proven that the microgrid designs are feasible and stable. The project proposal's economic superiority over the analyzed site's current solar photovoltaic/grid energy delivery system has also been proved through capital budgeting analysis. In comparison to the situation where no self-sufficiency limitation is enforced, establishing a baseline ego ratio of 100.0 percent raises microgrid lifetime expenses by just 14.0 percent. All parameterized inputs are considered to be deterministic in this study, which adds to the model's limitations in terms of dealing with model-inherent parametric uncertainty. The open source Smart API library was chosen as the platform's standard interface for any resources interacting with it. The project then moves on to an implementation phase, which is accompanied by a validation process, in which the platform's real operation is verified [117].

The best operating strategy based on a comprehensive active-reactive and thermal power scheduling in microgrids is investigated in this research, taking into account network constraints and following [118]. The microgrid structure under consideration comprises several types of combined heat power devices, boilers, and various types of DERs, including FC units, distributed generators, and MTs. In compared to grid-connected mode, the microgrid's total operation cost is significantly higher in isolated mode. It should be highlighted that future research might look at expanding the suggested model to include renewable resources such as photovoltaic and WT units. Because they offer particular circumstances for the functioning of DERs, Colombia's "National Indigenous Areas" (NIZ) are ideal labs for the creation of isolated microgrids. For the system to operate sustainably in the medium and long term, it is recommended that each DER be assigned roles and tasks. The infrastructure required for efficient and long-term DER incorporation should be identified and described. Regulatory regulations that stimulate the supply of auxiliary functions to the transmission system should be outlined. An incorporated actor-critic neural networking system is examined for power grid frequency management [119]. The suggested model is tested on a microgrid, with the outcomes assessed under several scenarios. For control, a deterministic learning technique is presented, as well as the estimation of a strategic utility function. The optimization of actor-sensor position and communication architecture will be investigated in a future study. For DER integration to be effective, correct operation and control, protection, and stability concerns must all be addressed.

Microgrids are a potential approach for combining various dispersed sources of energy into reduced voltage side networking systems in order to fulfill local demand while reducing carbon emissions. The aggregation of numerous DERs and energy storage technologies, each with its own operation and control technique, in order to provide a dependable and steady output, will be connected with a variety of technical issues [119]. These issues are regarded as obstacles to the practical and beneficial procedure of microgrids. An institution's building integrated photovoltaic model with fuel cells and distributed generators may deliver electricity in accordance with grid restrictions and function as a microgrid. The enhanced power system with distributed generation at TERI's retreat construction complex has resulted in a considerable increase in battery energy throughput, from 37.0 percent (in base scenario) to 72.0 percent. It has been discovered that distributed generation not only meets entire load demand during grid outages, but also increases yearly battery energy output. The use of multimodal indicators that take into consideration the financial, technological, ecological, and social elements of microgrids increased the community's and stakeholders' reaction capability. The microgrid's potential to foster the development and transformation of the regions in which it is located, as well as its interaction with the environment, are not expressly considered in resilience indices. With reference to [11], this study demonstrated and addressed an integrated framework for assessing the long-term durability of initiatives built on the notion of sociotechnical transformation.

Finally, microgrids are becoming more popular across the world as a novel idea that demonstrates the benefits of distributed renewable energy resources. With the proper use of converter control techniques, EMSs, and PQ improvement strategies, the DER architecture has been shown to be practical for the photovoltaic systems. The optimal interplay of electric vehicles and efficient energy storage system operating techniques improve the performance of DER microgrids, according to the review. The simulations corroborate previous research on microgrid frequency management and dependability, highlighting the relevance of energy storage system and electric vehicle interaction with the microgrid [7].

Literature review summary is shown in Table 1.

Authors comment on this paper: Future energy networks will encounter a variety of issues as the percentage of sustainable energy resources increases and the interaction with the other energy sectors expands. Solar, wind, energy storage, combined heat and power plants, electric cars, and smart circuits are becoming increasingly common. So, in this paper, we have covered many critical points regarding DERs as we evaluated the feasibility of using an actor-critical neural network with a distributed reinforcement learning control method to adjust for power grid frequency regulation. We also went over some of the most important components of a DER-based microgrid, as well as its significance and limitations. As for the limitations of this paper, we had limited access to the newest resources about this topic, so we had to utilize some of the older ones. Besides, more figures and statistical evidence are needed.

Table 1. Literature review summary.

Reference	Classification/Proposed Approach	Aim	Findings
[23]	meta-heuristic approach	This research presents a "robust microgrid capacity planning optimization framework" based on the Lévy-flight moth-flame optimization" method, which is a state-of-the-art meta-heuristic (MFOA)"	"Despite the fact that all of the meta-heuristics examined produced the same optimum system configuration, the Lévy-flight MFOA was able to generate a solution set (containing component sizes and total power exchanged with the utility grid) that gave a lower overall discounted system cost". Moreover, "Solving the microgrid sizing problem using meta-heuristics is computationally intensive since it requires calculating the year-long, hourly energy balance of the infrastructure mix chosen by each of the hundreds of search agents in the meta-heuristic of interest".
[13]	meta-heuristic approach	This work summarizes current relevant literatures on "hybrid distributed energy resources", such as wind, solar, combined cooling and heating and power, combined heating and power, geothermal, and hydro, published in the previous five years. It emphasizes the many approaches used as well as the issues that DER faces, which has now become a ground-breaking study subject for researchers to investigate and provide answers to.	"The overall cost of energy provided by DER systems is still relatively high, and efforts to minimize it should be made as soon as possible". For the purpose of accelerating technology and information transfer from the classroom to practice, there should be more cooperation between academics and industry. Finally, favorable rules and regulations should be in place to encourage extensive system installation and financial viability.
[117]	classical methods	The study outlines the minimal exchange of information requirements for some instances for the "integrated business platform", in order to enable new business opportunities for tracking, verifying, and implementation of microgrid and energy community flexibility services for distribution and transmission grid management.	The suggested data sharing platform is built in terms of the smart grid architectural model's specification of use cases. The necessity for an innovative information sharing platform in the energy system was identified in the study. The platform for information sharing was introduced and specified.
[118]	robust and stochastic programming approaches	"Determining the most transmission losses of active and reactive power as well as thermal conduction for DER and combined-heat-power-based microgrids that take into account network restrictions such as AC power flow limits".	In this study, network constraints are used to investigate an optimal cost structure based on a comprehensive active-reactive and thermal power scheduling in microgrids. In compared to grid-connected mode, the microgrid's total operation cost is significantly higher in isolated mode.

Table 1. *Cont.*

Reference	Classification/Proposed Approach	Aim	Findings
[40]	classical methods	This study begins with a discussion of the obstacles and possible advantages of incorporating DERs into distribution system operations. It also lists some common tactics for reducing the risk of these technologies being introduced into microgrids. The present status of every sort of energy source in Colombia is examined from the airwards. Finally, some fundamental ideas for enhancing the benefits of DER integration, as well as the limitations of islanded microgrid operation in said nation, are discussed.	Because they offer particular circumstances for the functioning of DERs, Colombia's "National Institute of Electricity" (NIZ) and "National Statistical Institute" (NIS) are suitable laboratories for the development of isolated microgrids. For the system to operate sustainably in the mid to long term, it is recommended that each DER be assigned roles and tasks. Regulatory regulations that stimulate the supply of auxiliary services to the electricity network should be outlined.
[119]	Distributed control approach	This chapter discusses numerous forms of DERs, including both distributed generation units and distributed energy storages, as well as their controls at various hierarchical levels. There have been descriptions of distributed generation technologies such as conventional/dispatchable and renewable energy/nondispatchable kinds. "Chemical energy storage, mechanical energy storage, electrical energy storage, thermal energy storage, and electrochemical energy storage are also briefly explored".	"The results of secondary level decentralized, centralized, and two-level hierarchical controllers used to a typical AC microgrid system are discussed". "Hierarchical controllers are more resilient than decentralized and centralized controllers, according to the findings".
[101]	Multi-agent technology based approach	To optimize the value of a linked microgrid with centralized organization that competes in the wholesale energy market, a discs optimization model is being developed (i.e., revenues-costs). "The sufficiency and constant security constraints of the microgrid, as well as its power losses, are integrated in the optimization model in addition to the operational limitations of DERs, which include both inter-temporal and non-inter-temporal kinds".	"The findings of the test microgrid results with and without losses reveal that ignoring energy loss causes erroneous results. The obtained average algorithm execution durations are suitable for microgrid day-ahead decision making, which is an off-line application with restricted time. However, in practice, by utilizing C++/C# software to simulate the program and employing multi-trading programming, the execution time may be significantly reduced".
[119]	Model predictive control	Proposing an "actor-critic neural network" that integrates a "distributed reinforcement learning control scheme to compensate frequency regulation of power grid".	The simulation findings show that the suggested method outperforms some actor-critic networking control strategies in frequency management of the power grid under specific conditions. The upper bound of long-term performance is calculated based on the analysis.
[4]	Classical methods	The major goal of this work is to provide energy management strategy(s) that take into account the lowest cost of generating while maximizing battery energy participation (i.e., "battery energy throughput") inside microgrid.	It has been discovered that good coordination of DERs with battery energy storage can help meet institutional vital load requirements and provide the complete load during grid outages
[94]	Mixed linear programming	Developing an investment strategy with the lowest total cost while meeting network operating constraints and the CO_2 emissions cap.	The results suggest that modeling the load as voltage-dependent and incorporating network reconfiguration into medium-term planning actions aids in the creation of an efficient network that is both eco friendly and has low total planning costs.

Table 1. *Cont.*

Reference	Classification/Proposed Approach	Aim	Findings
[95]	Robust and stochastic programming approaches	Proposing a two-stage energy management strategy based on receding horizon optimization to address the uncertainties and unpredictability of renewable energies and loads while minimizing operating costs.	The proposed two-stage energy management approach is resilient and effective in managing the functioning of the wind-PV-hydrogen-storage microgrid and removing WT, PV, and load uncertainties and variations. Furthermore, battery storage can lower the operating costs of electricity exchanged with the power grid and increase the effectiveness of the energy management model.
[96]	Classical methods	Proposing a novel multi-layered framework for deploying "heterogeneous automation and monitoring systems for microgrids".	The development of smart grids and microgrids is primarily promoting the digitalization of energy infrastructure. Their effective application overcomes hurdles, including research activities aimed at standardizing communication protocols and networking systems.

Author Contributions: Conceptualization, K.T.; N.B.; methodology, K.T.; software, N.B.; K.T.; N.B.; formal analysis, K.T.; investigation, K.T.; resources, N.B.; data curation, K.T.; writing—original draft preparation, N.B.; writing—review and editing, K.T.; visualization, K.T.; supervision, N.B.; project administration, K.T.; funding acquisition, K.T.; N.B. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

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