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Review

Optimization of DC, AC, and Hybrid AC/DC Microgrid-Based IoT Systems: A Review

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Abstract: Smart microgrids, as the foundations of the future smart grid, combine distinct Internet of Things (IoT) designs and technologies for applications that are designed to create, regulate, monitor, and protect the microgrid (MG), particularly as the IoT develops and evolves on a daily basis. A smart MG is a small grid that may operate individually or in tandem with the electric grid, and it is ideal for institutional, commercial, and industrial consumers, as well as urban and rural societies. A MG can operate in two methods (stand-alone and grid-connected), with the ability to transition between modes due to local grid faults, planned maintenance, expansions, deficits and failures in the host system, and other factors. Energy storage is the process of storing and converting energy that can be used for a variety of purposes, including voltage and frequency management, power backup, and cost optimization. IoT is designed to deliver solutions for optimal energy management, security protocols, control methods, and applications in the MG, with numerous distributed energy resources (DER) and interconnected loads. The use of IoT architecture for MG operations and controls is discussed in this research. With the use of power grid equipment and IoT-enabled technology, MGs are enabling local networks to give additional services on top of the essential supply of electricity to local networks that operate simultaneously or independently from the regional grid. Additionally, this review shows how hybrid AC/DC MGs are advantageous compared to AC and DC MGs. The state-of-the-art optimization techniques and trends in hybrid MG research are included in this work.

Keywords: smart microgrid; optimization; hybrid renewable energy source; internet of things; cost of electricity; information and communication technology

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Citation: Aljafari, B.; Vasantharaj, S.; Indragandhi, V.; Vaibhav, R. Optimization of DC, AC, and Hybrid AC/DC Microgrid-Based IoT Systems: A Review. *Energies* **2022**, *15*, 6813. https://doi.org/10.3390/en15186813

Academic Editor: Emilio Lorenzani

Received: 20 July 2022
Accepted: 14 September 2022
Published: 18 September 2022

1. Introduction

A MG is a group of electrical loads and small-scale generation resources that can meet all or part of the demand. MGs can be built individually (islanding mode) or in groups (connected to an upstream grid). If a MG is linked to the grid system, surplus intrinsic resource generation can be sold to the upstream grid to boost the MG profit. To increase efficacy, the majority of MG-producing units can be employed in a combined heat and power scheme [1]. The overview of MG generating and storage possibilities is presented in Table 1 [2].

Table 1. Summary of MG generation and its storage possibilities.

Table	Sources	Pros	Cons
Generation	Diesel and spark ignition reciprocating internal combustion engines [3]	• Dispatchable • Quick startup • Load-following • Can be used for CHP	• Nitrogen oxide and particulate emissions • Greenhouse gas emissions • Noise generation
	Micro-turbines [4]	• Dispatchable • Numerous fuel options • Fewer emissions • Mechanical easiness • CHP-capable	• Greenhouse gas emissions
	Fuel cells [5–7]	• Dispatchable • Zero on-site pollution • CHP-capable • Compared to micro-turbines; increased efficiency is obtainable	• Relatively expensive • Limited lifetime
	Renewable generation (solar PV, WT, and mini-hydro)	• Zero fuel cost • Zero emissions	• Without storage, it is not possible to transfer • Unpredictable and uncontrollable
Storage	Batteries [8]	• Long history of research and development	• Fewer charge–discharge cycles • Waste disposal
	Regenerative fuel cells [9]	• Decouple power and energy storage • Able to support a continuous operation at the maximum load and complete the discharge without risk of damage	• Relatively early stage of deployment
	Hydrogen from hydrolysis [10]	• Clean	• Relatively low end-to-end efficiency • Challenge to store hydrogen
	Kinetic energy storage [10]	• Fast response • High charge–discharge cycles • High efficiency	• Limited discharge time • High standing losses

Numerous hybrid approaches have been developed to examine the combined operation of the MG's micro-sources and storage facilities [11]. The MG administrator is in charge of the internal control of the MG's elements. The operators of the main grid, the market operator, or the regional transmission organization have no monitoring or control over the MG's micro-sources in this circumstance. A portion of the energy may be limited due to the MG's internal restrictions and inherent uncertainty.

The Internet of Energy (IoE) refers to the combination of IoT and MG technologies. The IoE takes advantage of the MG's bidirectional energy flow and information to gather data on power consumption and forecast future activities to improve energy efficiency and reduce net costs [12]. The MG relies on a number of IoT technologies. From the physical to the application layers, such technologies comprise the entire network protocols.

In 2017, the number of internet devices reached 8.4 billion, and by 2020, it is expected to reach 30 billion. The IoT is a system of these units that will communicate and share data. The IoT is at the zenith of its growth stage in the environment of MGs, with smart analytics promising a bright future. Energy-based analytic data sent from users to utilities have the ability to improve MG efficacy and minimize congestion, leading to increased power distribution reliability in a (future) 100% renewable energy paradigm.

The future MG will be made possible by the transition of a device-electric grid into a smart, self-healing bidirectional intelligent system [13]. Energy suppliers seem to be more interested in delivering efficient power, minimizing CO_2 emissions, helping to bring in green energy, and lowering prices while maximizing utility profits with these modern technologies. This IoT-enabled MG enterprise contributes to the global smart city mission. Table 2 shows the primary capabilities of a MG.

Table 2. Primary capabilities of a MG.

Functionality	Microgrid Description
Self-healing	A MG has the ability to assess, respond, and discover serious flaws very quickly. Smart metering systems are used to identify faulty circumstances and blackout scenarios.
Consumers motivation	Consumers can choose their suitable tariffs and more efficiently manage their energy usage. The case for enhanced energy consumer interaction and cost planning has been made.
Resist attack	The main challenges that a MG can readily combat are cyber-attacks and physical attacks. For MGs, several data conservation strategies have been implemented.
Improved power quality	Constant voltage is the most common consumer demand across all domestic, commercial, and industrial sectors. The MG has the ability to keep a constant voltage, therefore improving power quality.

The MG design [14] necessitates constant device monitoring, examination, and total management of the overall grid, in which large numbers of monitoring equipment of various sorts are placed at several power plants, transmission and distribution regions, and at the customer's side [15]. The IoT is described as collections of physical objects that are linked together via the internet [14,16].

Despite the commitment and availability of IoT technology, a MG will be impossible to accomplish in the future. Interconnectivity via communication devices, such as mobile phones, allow for quick decision-making through social cooperation and lowering application TCO. There are numerous advantages to cloud computing from a financial standpoint, where the TCO of a product is calculated from its acquisition, taking into account both service and running expenditures. The utility receives detailed information from smart meters and sensors, allowing it to prepare a compressed service order and the closest work to be delivered. Once the power goes out in the modern era of IoT and the MG junction, a message from the power line sensor is delivered quickly to the utility providers, who can then monitor the transformer operation. The IoT allows for more seamless activity and interactions between the two parties, resulting in a more effective wireless system. The primary contributions of this paper are to illustrate the benefits of hybrid AC/DC MGs over AC and DC MGs, to discuss the role of the IoT in the design and development of smart MGs, including benefits, challenges, and risks, and to expose a number of technologies, architectural designs, and applications that use the IoT with the goal of preserving and regulating innovative smart microgrids in accordance with contemporary optimization features and regulations. Figure 1 depicts the framework of this study.

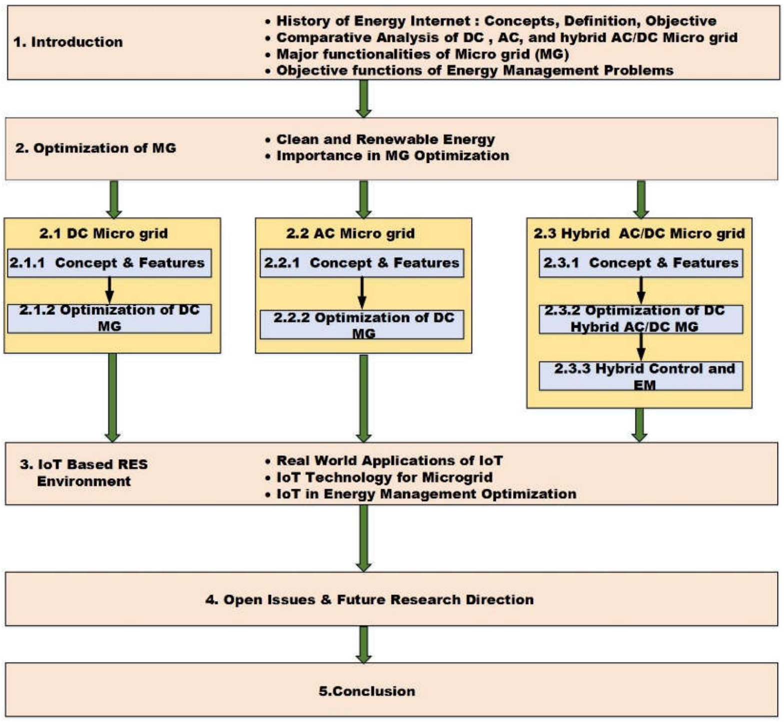

Figure 1. Framework of the paper.

2. Optimization of MG

Clean and renewable energy is advancing in order to achieve energy sustainability and harmonious growth in the economy and society. MGs are important tools for implementing clean and renewable energy. MG operation optimization has grown in importance as a study area. This study examines the recent improvements in MG operation optimization.

2.1. DC Microgrid

A DC MG has a DC bus that provides power to the DC loads coupled to it. Cell phones, internet routers, DVD players, battery-powered vacuum cleaners, wireless phones, and laptops are examples of low-power electronic devices. In a DC MG configuration, resources with DC output are simply coupled to the DC bus [17]. There are few converter elements necessary since these are more DC-generating RESs than AC-generating RESs. It increases the total efficacy of the DC MG.

2.1.1. Concept and Features

In this environment, the use of DC-operated technology in regular life has increased dramatically [18]. DC loads are generally linked to AC inputs because of an absence of independent DC supply networks at the consumer's end. Multiple conversions are required because the AC power is adjusted by converters for various DC load demands. Conversion losses and harmonics created by converters are steadily increasing, contaminating the power grid. The average power loss from these conversion procedures is 10–30% [19]. Regarding the principle of a MG—it was developed in response to an increased usage of DC systems and to handle low-powered DG resources. It complements the development of MG operations and improves the BESS [20]. Figure 2 shows the circuit of DC MG.

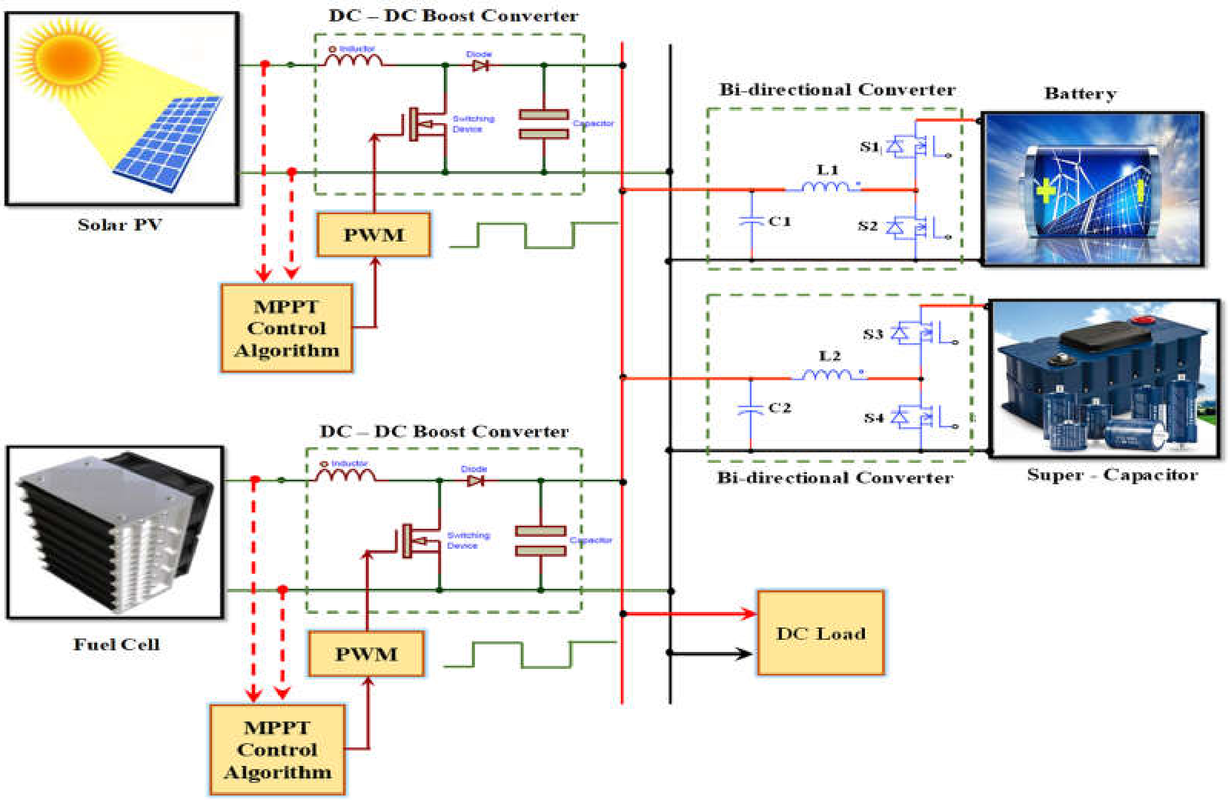

Figure 2. Circuit of DC MG.

If a BESS is attached to standard AC ports, massive conversion losses occur because of multiple conversion processes. As a result, BESS reliability has diminished. However, in a MG, the BESS is (most of the time) run within the DC bus. As a result, the losses experienced in the charge operations are considerably reduced, and the BESS behavior in a MG configuration is significantly enhanced. Electricity is presently unavailable to approximately 1.1 billion people [21], the majority of whom live in rural parts of Sub-Saharan Africa and Southeast Asia, as well as, to a smaller extent, the Middle East, Central Asia, and Latin America [22].

2.1.2. Optimization in DC MG

Thousands of SHSs [23] have been built in distant areas as a result of rural electrification schemes, typically in areas with no electricity grid, no regular wired telecommunication networks, and (mostly) poor availability by ordinary transport. SAPV systems are SHSs. Typically, crystalline-silicon PV modules are used in these setups. The most typical battery type used in a battery backup unit is lead-acid, and many tiny SHSs use charge controllers with PWM to optimize the charge current to the battery [24]. The lack of appropriate SHS monitoring and, hence, the inability to recognize O&M issues, can result in a severe reduction in the lifespans of PV systems, or even their removal from use [25]. The contributions of different optimization methods for DC MG are discussed in the various research works mentioned in Table 3.

Table 3. Optimization methods for DC MG.

Reference	Year	Optimization Algorithm/Method	Contribution	Drawbacks
[26]	2015	Decentralized voltage droop control	It is possible to achieve balanced and reliable load distribution, and it causes a steady-state voltage drift.	Lacks speed and robustness.
[27]	2020	Novel grasshopper	It includes energy conversion efficiency and oscillation minimization in terms of tracking time.	Contains more iterations and a slower rate of convergence.
[28]	2014	Game-theoretic cold-start	Reduces losses and reaches the steady-state operating point that is needed.	-
[29]	2016	Unified distributed dynamic optimizer	Voltage regulation and cost optimization by coordinating source voltages and optimally sharing power among sources.	-
[30]	2017	Optimal power flow strategy	Ohmic line loss, converter loss, and transmission loss are minimized.	An excess of reactive power can occur when the load is reduced.
[31]	2019	GA	Improves current sharing between the DGs, total loss minimization, and system voltage regulation.	Convergence speed is slower than other algorithms.
[32]	2020	Robust stability analysis	Stability analysis of a specific equilibrium under known constant power loads.	-
[33]	2020	Model predictive control	Provides economic, reliable, and rapid real-time control by solving the planned model in a time-sharing approach.	Cannot tune offline.
[34]	2020	Second-order Cone Optimization	It improves DC MG functioning while lowering operating costs.	-
[35]	2015	Newton Raphson method	Provides electrical power to areas that are off the grid. Optimizes the voltage level for efficiency, safety, and regulation.	Difficulty in calculating the derivative of a function.
[36]	2020	Adaptive differential evolution	Reduces DC MGs' operational costs and surpasses traditional GAs in terms of cost savings.	-
[37]	2019	Fuzzy control	The optimization time is significantly decreased, and the running cost is minimized.	Limited capability of current sharing.
[38]	2016	Frequency droop control	Even in the presence of unknown load demand and modeling errors, voltage regulation is achieved.	Poor transient characteristics.
[39]	2019	3G with IoT	The data logger could be put at a minimal cost to solve the challenge of monitoring PV systems in remote areas.	Speed is less compared to 4G.

Grid-connected PV plants typically require large expenditures, and the related data collecting systems allow for monitoring key variables and the execution of required maintenance operations without considerably increasing the overall cost of installation. Nevertheless, it is extremely complex to monitor the functioning of SHSs, owing to the reality that the necessary commercial data loggers are costlier in comparison to the overall system cost. As a result, more precise and independent external sources of data collecting systems must be developed at a smaller cost. Analytical control has progressively been implemented in small PV systems in recent years. Monitoring has been highlighted as one of the variables that lead to the viability of rural electrification programs since these efforts improve the lifetime of the system and reduce PV system failure, enhancing the user's confidence in the system. Table 4 lists the parameters in real-time PV systems that should be monitored.

Table 4. PV System parameters to be monitored in real-time.

General Parameters	Specific Parameters
Meteorology	Total irradiance Ambient temperature
PV array	Output voltage Output current Output power PV module temperature

2.2. AC Microgrid

An AC bus system connects the numerous energy-producing sources and loads in an AC MG network. AC MGs are often made up of dispersed generating units, such as renewables and traditional power production sources, such as engine-based generators. Such distributed generators are linked to an energy storage media, such as BESS, via an AC bus system. DC output is generated by renewable generators, such as solar PV and wind turbines. Through power electronic-based converters, this output can be transformed to AC.

2.2.1. Concept and Features

Wind energy has emerged as an essential alternate energy resource for power generation, owing to the diminishing reserves of global real-world resources and the progressive development of low-carbon and environmental protection principles. Wind energy is useful to the world's natural resources and ecology [40]. It is also conducive to sustainable economic development as a non-polluting and clean energy source [41]. According to studies, wind power generated roughly 12% of global electricity production in 2020 [42]. Wind energy is also expected to account for 22% of the worldwide power supply in 2030 [43]. Wind speed fluctuations and intermittency can have negative impacts on the stability and reliability of power grid operations, resulting in high costs and low efficiency. To increase the accuracy and reliability of WSP, it is critical to build strong prediction techniques. Physical techniques [44], traditional statistical strategies [45], spatial correlation strategies [46], and AI strategies [47] are the four basic kinds [48] of WSP methods that have been established in the last several decades [49]. Figure 3 depicts the AC MG circuit.

2.2.2. Optimization in AC MG

The following are the shortcomings of the forecasting strategies:

1. Physical methods are unable to successfully handle small time horizons; as a result, they are unable to produce efficient and precise solutions in short-term WSPs [50]. Furthermore, environment data must be updated on a regular basis, lengthening the time it takes to execute, and increasing the cost of resources.
2. With non-linear trends and unpredictable variations, conventional statistical methodologies fail to estimate wind speed TS. This is due to TS's prior assumption that all forms are linear. Furthermore, these techniques rely heavily on data for WSP under real-world conditions; as a result, if the original TS changes dramatically because of societal or ecological causes, forecasting errors will increase [51].
3. For this condition, substantial volumes of sophisticated monitoring of data are needed, and the predicting results will be inefficient due to data measurement limits and temporal delays.
4. Despite the usage of alternative methods, AI technologies were thoroughly investigated and are now being utilized to handle complex relationships and make accurate assumptions. These techniques can be used to capture the actual series in non-linear patterns.

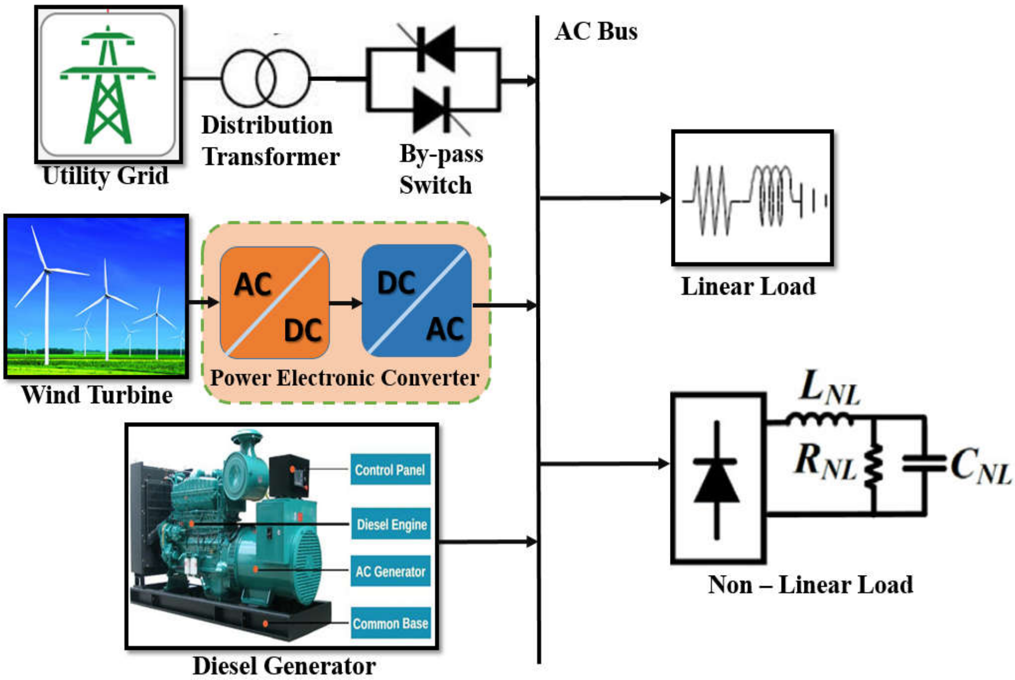

Figure 3. Circuit of AC MG.

The contributions of different optimization methods for AC MG are discussed in the various research works mentioned in Table 5; the parameters to be monitored in a real-time wind energy system are given in Table 6.

Table 5. Optimization methods in AC MG.

Reference	Year	Optimization Algorithm/Method	Contribution	Drawbacks
[52]	2020	Techno-economical	Single-axis and dual-axis solar trackers are used to test and optimize the performance of a stand-alone solar PV power system.	Does not consider a grid-connected PV system.
[53]	2018	GA	The TCE and LPSP of the load are both minimized simultaneously in order to solve the optimization challenge.	Cannot assure constant optimization response time.
[54]	2016	Frequency droop control	Keeps the MG system running at the necessary degree of dependability while lowering the net operating cost.	Communication systems are used to eliminate or reduce errors in reactive power sharing.
[55]	2020	Swarm intelligence	Enhances dynamic stability, improves dynamic response, and optimizes power quality.	Cannot work out the problems of the non-coordinate systems.
[56]	2020	Computational intelligence	Extremely effective at eliminating problems with power quality and transient responses.	More sensitive to fault resistance.
[57]	2017	Recursive algorithm	Recovers voltage and frequency synchronization, resulting in a more powerful control scheme even in noisy environments.	Complex algorithm.
[58]	2018	Pontryagin's minimum principle	Optimizes parallel connected inverter systems in an islanded MG.	It specifies only the need to hold over a particular trajectory.

Table 5. *Cont.*

Reference	Year	Optimization Algorithm/Method	Contribution	Drawbacks
[59]	2014	Stochastic energy management technique	RES has a great impact on the optimal operation and programming of interconnected MGs. Reduces the cost functions of AC MGs	Network constraints can affect the optimal scheduling of units.
[60]	2016	Sliding mode direct voltage control	Improves the system's disturbance rejection and power distribution accuracy.	Complex and low speed.
[61]	2016	Neuro-fuzzy controller	Frequency control without any storage.	The structure is not totally interpretable.
[62]	2017	Day-ahead MG EM optimization	The O&M costs of lithium batteries and fuel cells, the interruptible compensation of interruptible loads, and the price of energy, are all part of the target function.	-
[63]	2018	Iterative consistency algorithm	Increases the AC MG control's durability and flexibility, and only requires little communication between surrounding agents to achieve a global optimum.	Sensitive to communication failure.

Table 6. Factors to be monitored in real-time wind energy (a survey of cyber-physical advances).

General Parameters	Specific Parameters
Environmental	Wind Humidity Lighting Icing
Mechanical	Positions Speed Angle Stress Strain
Electrical	Voltage Current Power factor Frequency Faults
Temperature	Bearings Oil Windings Electronic components
Fluid	Pressure, level, flow

2.3. Challenges, Need for a Hybrid AC/DC MG, and Its Implementation

The main hurdles for successfully implementing hybrid AC/DC generation systems are described in detail in this section. In addition, the current scenario's solutions to the difficulties are offered. The second portion of the section discusses the need for AC/DC MG integration as well as its advantages. Figure 4 shows the hybrid renewable energy generation by source, measured in terawatt-hour (TWh).

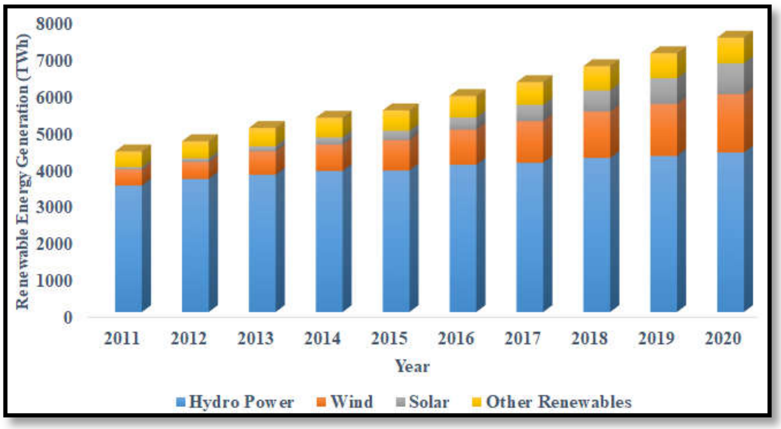

Figure 4. Hybrid renewable energy generation. (**Source:** Statistical review of world energy).

2.3.1. Concept and Features

One of the most intriguing strategies in the evolution of the MG principle in the present distribution network is the hybrid AC/DC MG. Figure 5 depicts a typical hybrid MG structure, with the AC and DC networks. Several devices can be observed in the diagram: PV, fuel cell, a diesel generator, DG and ESS units, VSD, AC and DC loads, etc. Interlinking converters have been used to connect AC and DC sub-grids. This arrangement confines greater interfacing, which in turn minimizes the cost and improves overall efficiency. This architecture is the most appealing option for a future MG framework.

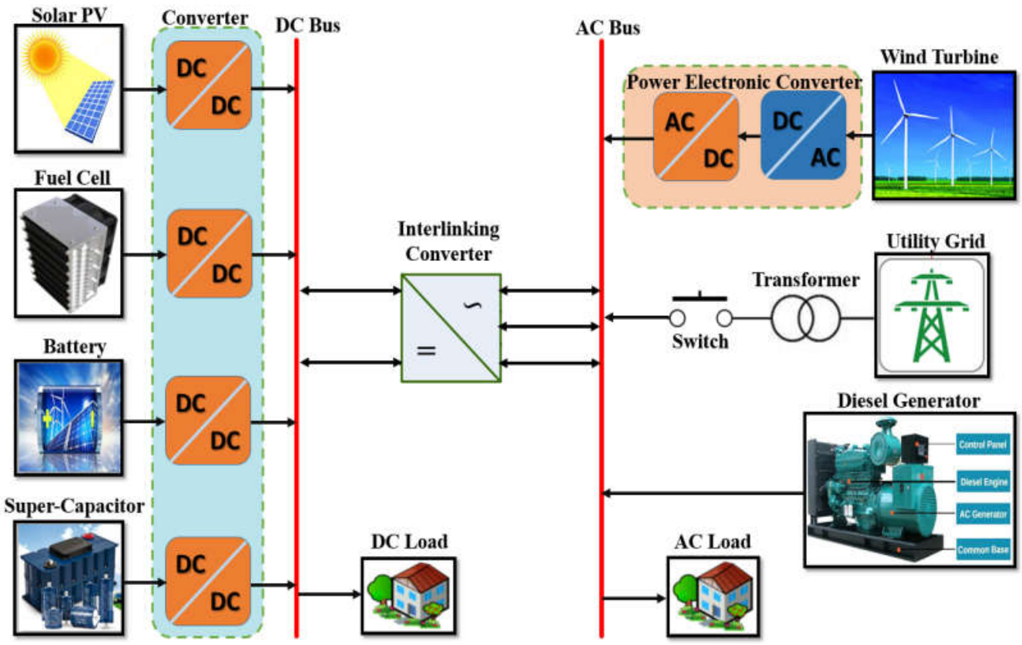

Figure 5. Hybrid AC/DC MG with interlinking converter.

The following are the most significant advantages of these MGs:

Integration: Devices that are powered by AC or DC are directly interconnected with the fewest interfacing devices possible, eliminating conversion stages and, thereby, energy losses.

Synchronization: Because the generation and storage devices are directly coupled to the AC or DC network, there is no need for them to be synchronized. As a result, the device's control method is simplified.

Voltage transformation: Use of such transformers on the AC side can be used to modify voltage levels in a straightforward manner. On the DC side, DC–DC converters are used to conduct the conversion.

Economic feasibility: By adding a power converter to the existing distribution grid and a communication network for linked devices, a hybrid MG can be created. With the use of a power converter, the net prices are higher than that of AC MGs. Although, if the number of connected devices grows, the expenditure will be repaid more quickly because the overall number of interfacing converters will decrease.

2.3.2. Optimization of Hybrid AC/DC MG

Integration of renewable energy resources, such as solar panels, batteries, and other energy storage devices with low voltage systems, will be a viable method for reducing multiple energy conversion losses in the proposed system.

The utilization of RESs has rapidly increased to address the critical concerns of increasing energy demand and global warming [64,65] as a result of increasing energy consumption, which is expected to reach 53% by 2035 [66]. For instance, HMGS [67] delivers energy delivery to rural places where essential T&D amenities are not accessible or costlier to install. When three features are met, DERs can be considered a MG: electrical boundaries are set, an EMS is included, and the power generation capacity must surpass the peak critical load [68,69]. In [70], a novel load flow algorithm for AC/DC distribution systems that makes use of matrix algebra and graph theory is presented. To find load flow solutions, four designed matrices (the loads beyond the branch matrix, the path impedance matrix, the path drop matrix, and the slack bus to other buses drop matrix), as well as basic matrix operations, are used. Similarly, in [71], AC/DC hybrid distribution systems provide a single load flow (LF) model (DSs). The suggested approach can be used in hybrid distribution systems (DSs) that have AC/DC buses and AC/DC lines configured in a wide variety of ways. Additionally, a new DS bus category is presented for LF analysis. There are a number of important factors to consider when making a decision. First, the COE that relates to the cost of operation to fulfill the load demand. Second the stability needs to be at the highest level so that the power supply breakdowns are prevented. The LPSP, which will be discussed in the following sessions, is one of the metrics that can be used to describe HMGS reliability.

(i) Designing objectives with ESS.

The imbalance between peak demand and generation can be smoothed out by energy storage. As a result, matching electricity generating sources for the setup of an HRES is simply a designer's optimization challenge with several limitations to meet. The design techniques must strike a balance between reliability and cost [72]. Supply security issues were also taken into account in the design of the MG design in a recent study [73], which defined a probability adequacy index. Leou [74] analyzed installation costs, O&M costs, and income, considering energy price arbitrage for minimizing transmission access costs and postponing facility construction. Sundararagavan [75] conducted a cost analysis of eleven types of energy storage technology for essential applications linked with a wind farm combined with an electric grid.

Chedid et al. [76] developed the core of a computer-assisted evaluation tool that can assist designers in determining the best design of a hybrid wind–solar–diesel generator–battery power system for independent- or grid-connected applications. Batteries, at relatively low costs and with widespread availability, are the most widely used components in hybrid systems. Tewari et al. [77] looked at a nNaS battery system for transferring power generation from off-peak to on-peak, as well as ramp rate limitation to smooth out wind output. Using model predictive control theory, Khalid [78] devised a new semi-distributed approach that efficiently lowers the BESS capacity required, lowering the total system cost. Brekken et al. [79] employed flow batteries in conjunction with an ANN method to handle the uncertainty in wind output and reduce energy prices even further. The uncertainties in an HRES integrating PV–wind–diesel and a hydrogen-based ESS were investigated by Giannakoudis et al. [80].

The first was a typical strategy relying on the battery's state of charge, and the second was an enhanced ANN algorithm that was evaluated based on energy storage costs. According to the findings, the hybrid battery–hydrogen system storage costs 48% less than a hydrogen-alone system and just 9% less than a traditional battery-only system. Katsigiannis, on the other hand, used NSGA-II optimization and discovered that the hydrogen-based system had higher LCE and emissions than the lead–acid-based system [81]. Choi [82] aimed to reduce battery charging current variations and energy losses in super-capacitors by optimizing a battery/super-capacitor hybrid ESS. Thounthong et al. [83] developed a novel approach for combining a super-capacitor with a hybrid PV–fuel cell power plant as an additional source and short-term storage units.

(ii) Sizing objectives.

The optimal sizing of producing units is critical for efficiently and economically utilizing RESs. With an appropriate and complete utilization of the HRES components, the sizing optimization approaches can help to ensure the cheapest investment. Economic and environmental objectives are the most typical goals considered while sizing an HRES. Nehrir et al. [84] examined several methods for system setup, unit sizing, control, and energy management of hybrid systems under investigation. Details about HRES initiatives being implemented around the world were also compiled. Bernal-Agustin et al. [85] and Zhou [86] have also provided their analyses on HRES design, simulation, and control employing PV, wind, and diesel with battery storage. Luna-Rubio provided a review of sizing approaches, including several metrics that were adjusted for maximum performance at the lowest cost [87]. Elma and Selamogullari [88] investigated a stand-alone hybrid system that met the electrical requirements of a residential house.

Numerous research has taken into account economic system parameters, such as LPSP, LCOE, and fuel costs while sizing. With LPSP as the main restriction, Hongxing built and studied a hybrid solar–wind–battery system optimal model for lowering system costs [89,90]. Ekren [91] investigated the difficulty in scaling a PV/Wind/BESS system for use in a GSM station in Turkey. RSM was used to address the sizing problem, and a minimum energy cost of USD 37,033.9 was attained. A siting strategy was devised by comparing this COE to transmission line expenses using the break-even analysis [92].

Using a controlled elitist GA, Reference [93] proposed a triple multi-objective optimization technique to assist developers in taking into account both environmental and economic issues. LCC, EE, and LPSP indicators were merged in the optimal solution. Di-Silvestre et al. [94] established a multi-objective optimum operation using a distinct layered technique. In Reference [95], decision support tools based on the fuzzy technique for order preference by similarity to ideal situation (TOPSIS) and level diagrams were used to build HRES. Arnette [96] devised a multi-objective linear programming approach for HRES planning that allows the decision maker to balance generation costs and emissions under a variety of operating situations. As a result, the wind and solar potential capabilities were assessed separately, taking into account the sizing objectives. Zhang et al. [97] introduced a unique technique for optimizing power dispatch simulations in a PV–battery–diesel system by reducing LCE, which also took into account maintenance costs, capital depreciation costs, pollution damage costs, and fuel costs. Tan et al. [98] introduced a new optimization model for DG siting and size that took into account technical factors including grid VA need, voltage profile, real power losses, and so on.

2.3.3. HRES Control and Energy Management

In order to attain the needed quality power at predefined costs, optimization approaches play a critical part in the functioning of an HRES. Any portion of the HRES can benefit from optimization. The main functional areas for optimization are generation controls such as power dispatch control, energy management decision-making controls, operation controls for power quality and cost control, and MPPT control systems. The following are some examples of the state-of-the-art in control and management.

(i) Power quality and cost control.

Power conditioning devices such as STATCOM and quality management procedures in distribution systems increase power quality [99–101]. It is critical to install them in the best possible location and execute them properly in order to save money and improve efficiency [102]. Serban [103] devised a system for optimization and testing of the frequency control mechanism in MGs, using BESS. By incorporating an ESS in small, isolated power systems, Sigrist [104] calculated the economic advantage of primary frequency control reserve and peak-shaving generation, resulting in a total cost savings of 23.2 Mio €/year and an internal rate of return of 7.25 percent. In Agios Efstratios, Greece, Vrettos et al. [105] investigated the infiltration of WT-ESS into an emerging diesel unit. Applying GA to optimize the LCOE, it was discovered that a 10–15% reduction in LCOE could be obtained with a 75% RES saturation level. In 2013, Zhao [106] addressed the lifetime properties of lead–acid batteries while doing multi-objective optimization to minimize power generation costs and increase the usable life of lead-acid batteries for a similar HRES MG. It has been demonstrated that a higher RES penetration level might result in a 30% drop in total expenditures. The control objectives defined by Younsi et al. [107] are to fulfill the power sought by the AC grid, control the transfer of energy among the hybrid system and the AC grid, optimize the use of wind energy, and minimize fuel costs of diesel generators. Arabali et al. [108] applied GA to a hybrid system that served a single HVAC load, analyzing the cost and efficiency of operation during different scenarios. With the introduction of commercial power system simulators that include powerful analytical and visualization tools, studying power flow controls in a MG has become considerably simpler [109,110].

(ii) Power dispatch control.

In power system applications, such as economic dispatch, unit commitment, and generation scheduling, optimization approaches are becoming increasingly popular. Conti et al. [111] developed an optimization approach for DG and ESS dispatch in a medium-voltage islanded MG with the goal of lowering emissions and operational costs. Zhang et al. [112] proposed a unique power scheduling technique for reducing utility costs of dispatchable loads, worst transaction costs due to renewable source uncertainty, and generation and storage costs. When combined with an HRES, CHP significantly increases efficacy and pays for itself. A CHP-based DG MG with ESS and three different forms of thermal power generation units and DRPs was studied in Reference [113]. Maa et al. [114] conducted a viability analysis on a residential MG system with a hybrid PV–WT and CHP generator. For power dispatching challenges, most new methods use commercial simulators, such as Power World [109]. It simplifies inquiries and the evaluation of complex market policies. MILP was a commercially available solver-based method that avoided the use of complex heuristics or decomposition methodologies [115].

(iii) Energy management control

The efficiency of HRES subsystems can be improved by appropriate resource management [116,117]. Zhao et al. [118] adjusted the reactive power output of a wind farm and the network infrastructure at the same time to reduce system actual power losses and bus voltage deviations, resulting in enhanced power control and voltage profile. Trifkovic et al. [119] used decentralized adaptive model prediction control and decision-making techniques to describe a power management strategy for a wind–PV–electrolyzer–fuel cell integrated standalone system. It was discovered that operating the electrolyzer at a lower power level increased the efficiency of the renewable energy produced, resulting in more hydrogen production. Table 7 shows the optimization methods used in a hybrid AC/DC MG.

CAES results in a 43% higher operating profitability and 6.7% less net load serving costs, even when capital expenses are not taken into account. For enlightening energy management techniques, a mixture of optimization techniques and AI methods has also been tried. Multi-objective smart power management tries to reduce a MG's operating costs and emissions while taking into consideration pre-operational variables such as future renewable energy supply and load demand. For optimal operation of an HRES system, controlling variables coming from renewable generation and load demand projections are also examined. Hong's PEM was used by Mohammadi et al. [120] to optimize a MG by modeling the uncertainty in load demands, market prices, and renewable energy generation. In Reference [121], rather than using Hong's estimate, an optimal stochastic approach was used, which included the usage of probability density functions for each unknown parameter and roulette wheel mechanism scenarios. The stochastic approach captured roughly three times the number of uncertainties as the deterministic approach.

Table 7. Optimization methods in Hybrid AC/DC MG.

Reference	Year	Optimization Algorithm/Method	Contribution
[122]	2013	Discrete harmony search	Optimizes the size of wind–PV hybrid energy systems.
[123]	2019	GA	Optimize a hybrid solar-wind energy system with storage for a remote island.
[124]	2011	Iterative optimization technique	For power reliability and system costs.
[125]	2012	PSO	Achieve the lowest MG cost possible during an interlinked operation by optimizing the local DG generation, and power exchanges with the main distribution grid.
[126]	2013	GA	The proposed BMS reduces operating expenses while accounting for various battery operating points and aging factors.
[127]	2014	Techno-economic approach	Optimizes the size of the main distribution system.
[128]	2018	Interval optimization approach	More variation profits are lost, but a smaller amount of average profit is lost, making the retailer more resilient to pricing volatility in the pool market.
[129]	2018	Annealing-chaotic search	A hybrid reverse osmosis desalination plant fueled by solar and wind energy was designed using an optimization approach.
[130]	2019	Wind-driven optimization	Excellent rate of success and high efficiency in monitoring time.
[131]	2019	Grasshopper optimization	According to the DPSP and COE, develops the best system configuration for supplying energy demand efficiently.
[132]	2020	Multi-objective PSO	Reduces the LCOE and increases the transmission channel utilization rate.
[133]	2020	Chance Constraint optimal power flow method	Proposes a two-stage voltage control system for a combined central and local voltage control mechanism.
[134]	2017	Multi-objective PSO	Every region determines the best system configuration and component size.
[135]	2018	Nelder–Mead—cuckoo search	By controlling the power output of RES, the power losses in hybrid AC/DC MG systems can be reduced.
[136]	2013	Multi-objective	Minimizes lifecycle costs and CO_2 emissions from the system.
[137]	2021	GA	Minimizes conventional distribution network losses in residential areas. Uses a time-of-use tariff system, and lowers the COE.
[138]	2016	GA	Minimizes DS installation and operation costs.
[139]	2018	Newton—Raphson algorithm	Models converter losses because it will lead to different load flow values.

Table 7. *Cont.*

Reference	Year	Optimization Algorithm/Method	Contribution
[140]	2020	Graph-theoretic-based approach	Tested on several AC/DC test networks that include different operating modes of power converters and various models of DGs, which prove the feasibility and legitimacy of the technique.

2.3.4. Future Prospects of Hybrid AC/DC Microgrid

The flexible control capabilities of AC/DC hybrid DER systems are further utilized as one of the development directions of the power distribution system for the energy internet. In future studies, researchers might find great interest in investigating cooperative planning with gas, heat, and cooling systems within the context of multi-energy complementarity [141]. The important principles for the futuristic approach in an AC/DC microgrid environment for a smart and intelligent system with uninterrupted, secure, and safe power flow are listed below [142].

- Communications infrastructure that is functional and affordable.
- Enhancing energy efficiency via a cutting-edge communication system that uses clever relaying techniques and coordinated multipoint algorithms.
- Using linked communication methods, such as optical wireless.
- Self-healing should be sufficient in a hybrid environment.
- Advanced algorithms for compelling current to zero before it is interrupted by CBs.
- Robust AC/DC interface should be designed.
- Limitation of SCC should be taken care of.
- Smooth conversion between microgrid mode of operations.

3. IoT-Based Hybrid AC/DC RES Environment

Communication networks are critical components of HRES because they allow data to flow between data sources (sensors and meters), control centers, and controllers. The data flow from various elements establishes the system architecture in addition to facilitating the control operation and remote monitoring [143]. Sensing, communication, processing, and actuation will all benefit from IoT technology, which will facilitate a variety of MG applications. This research concentrates on the amount of communication between the HRES local controller and the MG control center, in which the condition of various RESs and loads can be gathered and reported to a central controller, which decides the required system action.

3.1. Real World Applications of IoT

From agriculture to health care, IoT services and intelligence can alter the lives of ordinary people. As this innovation [144] advances at a breakneck pace, it will logically anticipate population requirements and benefit society as a whole. The real-world implementations of IoT are depicted in Figure 6, which range from the retail industry to health services. In terms of IoT, the most popular phrase is "smart home." It has emerged as a progressive component in the residential sector, and smart homes are expected to be as common as smartphones in the future. Smart home devices [145] will gain branded household products as energy, and automation progresses, reducing consumers' time and, ultimately, money. This is a critical aspect for certain smart items to communicate digitally in order to provide users with a cost-effective experience. IoT devices are always being improved to make them more compact and energy efficient.

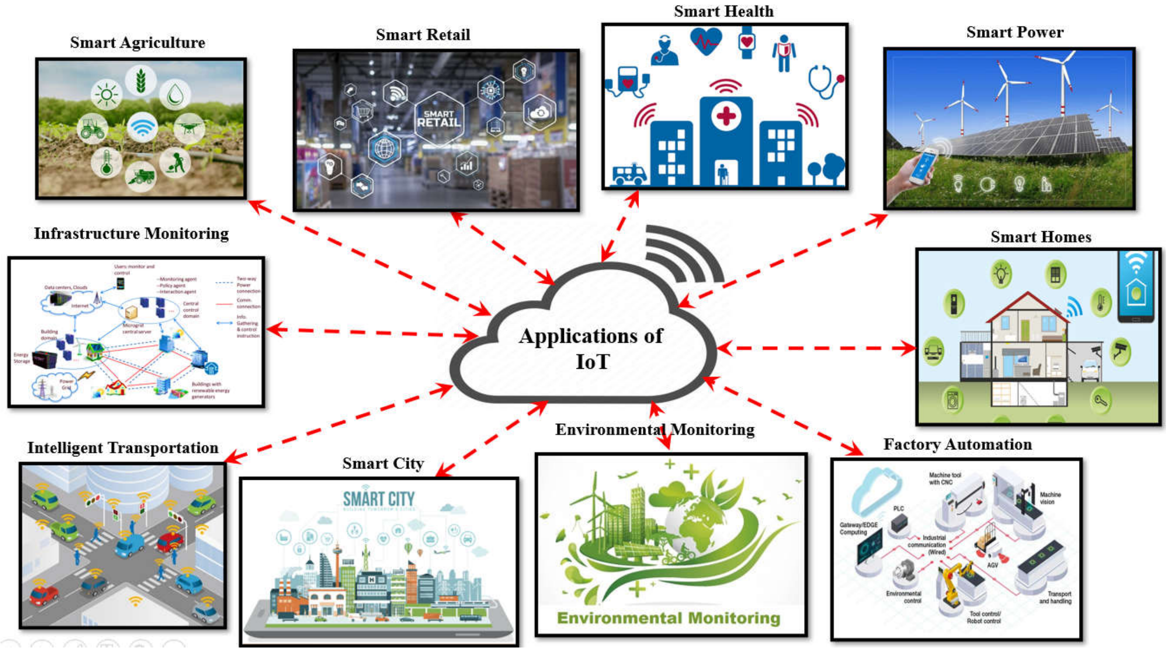

Figure 6. IoT in the real world.

As per a Forbes survey [146], leading brand businesses are expected to sell over 411 million wearables on the digital market by 2020. In article [147], the future necessity for addressing those uncertainties is explored using an IoT-based architecture. With the advancement of IoT technology, the theory of smart cities is gaining popularity. The requirement to analyze necessary protocols for urban IoT platforms [148,149] with optimized speed routing algorithms in smart streets for specific situations must be prepared for in the future.

In the automotive digital industry, IoT provides the way for vehicles that are more stable and robust in terms of performance. Connected automobiles with IoT capabilities use pre-stored inputs based on several sensors to regulate the vehicle's functioning more independently. IoT-enabled automotive revolution brought together larger branded firms from both the IT and automotive industries. The industrial sector is the next most important market for economic growth. With the growth of analytics, big data [150], progressive software resources, and enhanced sensors, Industrial IoT has the potential to empower whole sectors. Figure 7 shows that the majority of the market is focused on smart cities and industrial IoT.

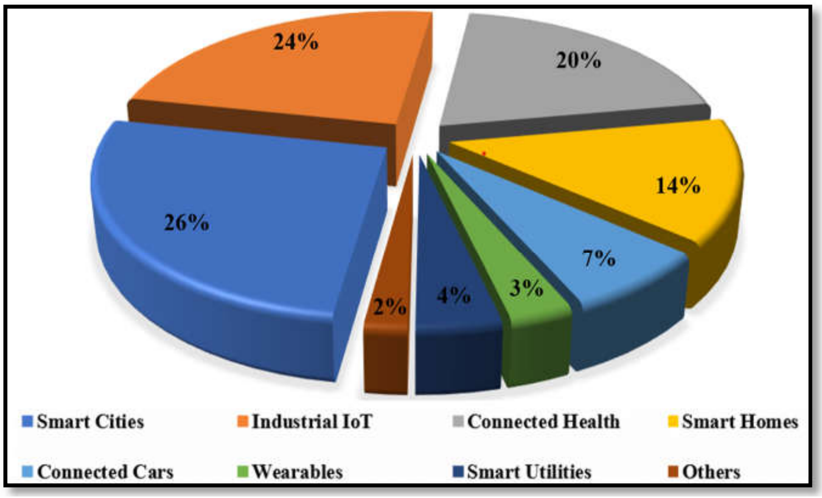

Figure 7. General market structure of IoT technologies [151].

By actively communicating with industrial data, the IoT helps create a more trustworthy solution. As a result, industries may more efficiently address inefficiencies and identify issues earlier, resulting in higher profits and productivity. In the near future, industrial IoT will focus on sensor cloud-based integrity communication [152]. New agricultural innovation is desperately required to meet the increasing demand for food supply. Only by combining innovative agronomics techniques with end-to-end IoT technologies can this be possible. Crop monitoring is performed effectively, and the persistence of a range of crops may be done in a very fair manner, resulting in more efficient water management.

Another important sector where IoT solutions are becoming more prevalent is healthcare, which aims to provide high-quality and timely services to patients. Patients and doctors can engage with each other on a routine basis because of the IoT. The global market can be expanded as a result of the use of various IoT-based smart devices that have high consumer satisfaction. With this technology, the requirements for luxury, security, safety, and cost-effectiveness can be met. Table 8 depicts the fundamental characteristics of IoT, as well as its benefits and drawbacks.

Table 8. Benefits and drawbacks of IoT.

Features	Pros of IoT	Cons of IoT	Possible Concerns towards the Remedy
Automation	The key benefit is that it can keep the entire M2M communication process transparent.	-	-
Efficacy	The system's performance is enhanced, and the presence of a M2M interface allows workers to focus on other tasks.	-	-
Security and Privacy	-	The data stored are immediately available because many equipment and services are dynamically connected to one another. The data are susceptible to hackers and unauthorized concerns.	Concentrating on more data verification tools can help solve this problem.
Communication	By talking with devices [3 N] on a daily basis, IoT develops a platform that enhances the quality and time factors.	-	-
Compatibility	-	Currently, few worldwide compatibility standards; it is difficult for suppliers and consumers to interface with services.	Similar protocols for multiple sectors, such as commercial, industrial, and residential, might be used to generate new standards.
Savings of Cost	IoT solutions aid in the development of more expensive systems for day-to-day activities in a variety of sectors, as well as efficient systems.	-	-
Difficulty	-	Because a huge network is interconnected, even minor software and hardware component failures can cause system harm.	Rapid failures at node junctions can be detected by a central control center, and necessary corrective action can be taken.

Table 8. *Cont.*

Features	Pros of IoT	Cons of IoT	Possible Concerns towards the Remedy
Instant data access	Immediate access to data in a timely manner aids in the efficient management of the process. This, in turn, makes people's lives easier and more comfortable.	-	-
Fewer jobs and technologically dependent life	-	As the number of M2M interfaces grows and automation control is implemented, the need for personnel decreases, and technology reduces human interaction.	Different control centers might be set up with the help of new competent staff.

3.2. IoT Technologies for MG

In today's world, several IoT-based solutions are accessible to meet the demands of MG applications. Despite the fact that numerous communication technologies are suitable, there are currently few standards for the effective implementation of MG. IoT technologies are mostly employed in MG for long-range bi-directional data exchange among the utility and the user via IoT-based equipment, such as smart meters. In most cases, IoT-based MG systems require advanced wireless technologies rather than wired-based technologies to alleviate the difficulty of long-distance data transfer. Certain wired methods [153], are necessary for the event of signal attenuation-related interference because these technologies will not depend on batteries to operate.

Wireless methods can be used to transfer data between smart meters and IoT-enabled devices, as shown in Table 9. Various wireless communication technologies based on IoT are detailed in this table, along with their coverage ranges, which can be utilized for MG systems. IoT can facilitate the flow of data between utility data centers and different smart meters. Different wireless techniques are required to obtain these systems together, which presents a difficult microcosm for IoT-based MG systems. Long-range connectivity is demonstrated by cellular-based networks such as LoRa [154] and Sigfox [155], which are used to build the backbone network for future grids with cloud-based service domains. MG systems will primarily focus on exhibiting long-range connectivity [156,157] and establishing a network structure with cloud-based application areas.

Table 9. Wireless technology based on the IoTs with an MG coverage range.

Technology	Usage of the Protocol Needed	Pros	Cons	MG Application
IoT-based wireless Technology	Zigbee	• It has 16 channels with 2.4 GHz and 5 MHz of bandwidth. • Less complexity. • Cost of deployment is less. • Power utilization is low.	• It has a very short range. • Processes fewer data capabilities. • Data rate transfer is less.	• Home automation • Coverage range—to 100 m.
	Long range WAN (LoRaWAN)	• Long-range connectivity • Bidirectional communication with less interface. • Provides virtual channels for the improvement of IoT gateways.	• No drawbacks in terms of data transfer.	• Monitors the transmission line networks with an online facility. • Coverage range—to 15 km.
	Z-wave	• Latency found to be low. • Less interference with other wireless devices.	• Start range. • Less suitable for NAN.	• Smart home automation. • Coverage range—30 m.

Table 9. *Cont.*

Technology	Usage of the Protocol Needed	Pros	Cons	MG Application
	IPv6 over low-power wireless personal area networks (6LoWPAN)	• Robust technology. • Less power needed. • Connectivity easier with large wireless platforms.	• Short range. • Less data rate transfer.	• Smart meter. • Coverage range—to 100 m
	Thread	• Low power. • More secure. • Connectivity easier.	• Less data rate transfer.	• Smart meter
	sigFox	• Low levels of data transfer speed. • Less power needed. • More connectivity.	• No drawbacks in terms of data transfer.	• Smart home automation. • Coverage range—10 to 30 km.

The majority of MG systems center on NAN and WAN [155], which need maximum range and minimum power technologies. For such technologies, LoRaWAN [158] emerges as a potential player. Aside from these wireless technologies, it is important to remember that determining the optimum technology for MG is impossible because most of these wireless technologies are possible candidates for MG-based applications. Several wired technologies, such as DSL [159] and power line communications [160–164], are widely employed in rural settings, and are paving the way for smarter technology. Table 10 depicts IoT device which is connected worldwide.

Table 10. IoT devices connected worldwide.

Connected Devices	Year
0.2 million	1999
80 million	2010
9.0 billion	2013
1.0 trillion	2025

3.3. IoT in Energy Management Optimization

MGs are becoming more popular as a result of renewable energy projects around the world. They have a lot of benefits, but they also have a lot of drawbacks, especially when it comes to working with traditional MG's. SEMS are developed to assist grid operators in managing energy production and consumption as efficiently as possible in order to save money, minimize CO_2 emissions, and ensure that electrical networks remain stable at all times. In the last few years, the IoT industry has developed quickly, with the advent of very effective open source IoT platforms that are especially well adapted to the development of SEMS. The most significant benefit of the open source IoT strategy is its vendor independence and ability to adapt to changing market conditions [165]. This gives grid operators more control over their assets, allows them to stay current with market demands, and allows them to improve or expand their EMSs to meet their needs. Figure 8 shows the IoT-based optimal EMS for MG.

3.3.1. IoT and Wind Energy Optimization

In terms of efficiency and size, wind technologies are quickly evolving. The primary stumbling block to the growth of wind energy is the intrinsic intermittency of these resources. As a result, if wind units have a high infiltration in fulfilling demand, extreme inequalities could jeopardize the system's security. Furthermore, IoT technology combined with ICT infrastructures enables wind farm owners to plan precise predictive maintenance plans, avoiding costly downtime. On-time maintenance, for example, can lower the LCOE index for wind assets [166], which represents the net present value of the unit–cost of power throughout the turbine's lifespan.

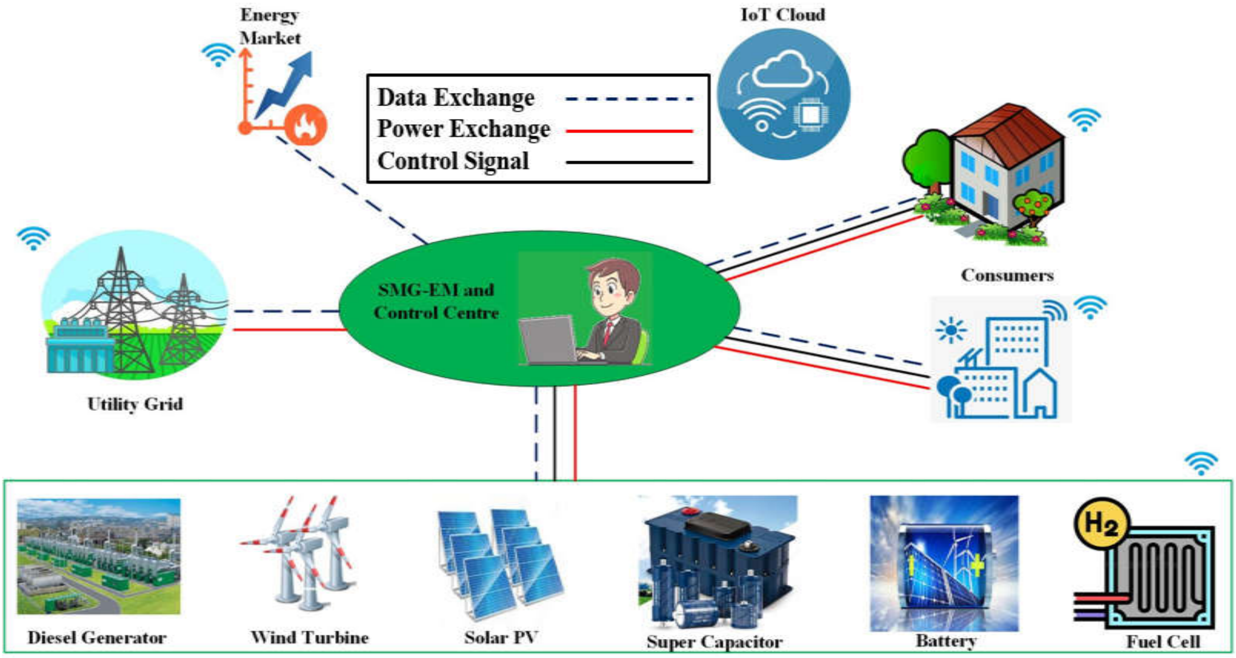

Figure 8. IoT-based optimal energy management and control for a MG.

The need for IoT in the wind energy industry stems from the fact that data related to WTs and wind farms must be obtained and evaluated quickly. Offshore wind farm data transmission delays and limited bandwidth for relaying information to remote areas were two major concerns that can be addressed right now. As a result, decision-making processes can be sped up or automated if important information can be gathered and processed in real time. The use of IoT technologies in the wind industry emphasizes the necessity for better comprehensive strategies for designing and operating wind farms and also installing and maintaining turbines that are cost-effective, secure, and safe. There are a lot of sensors and actuators in the WT controller layer. Each fundamental component's health and function can be reported by the sensors. Using a series of actuators, the control system regulates and configures the components.

The controller accepts sensor information and utilizes power amplifiers to convey electric, hydraulic, and mechanical signals and instructions. Cyber-physical devices must be combined to link the physical layer of wind turbines to the cyber layer via a network architecture. The network, condition-monitoring system, and SCADA make up the cyber layer. The design of a communication network, particularly for offshore wind farms, is largely dependent on local conditions. To connect to a LAN, each turbine must be fitted with an RTU. Such devices share data with a central data center that uses a cloud-based WAN.

All WTs in a wind farm are furnished with IoT-based-distributed intelligence systems and embedded systems that benefit from WSN, as well as M2M communication under cloud-based systems that transmit information to servers using internet-enabled and open communication protocols, and can be controlled and regulated using mobile HMIs or unified computer-aided interfaces. The IoT-based controlling system is said to be more expensive than current SCADA platforms, but due to the higher sampling rate and data frequency, it is said to be more effective at diagnosing. The IEC61400-25 standard, which improves the standardization of the data exchange gateway, diagnostics, autonomy, and extensibility was designed in order to execute unified monitoring and information exchange.

3.3.2. IoT and Solar Energy Optimization

Solar energy offers the greatest potential for renewable energy power generation. As a result, this source is expected to be a significant provider of future clean power systems. Solar panels, switches, wiring, mounting systems, and inverters make up a PV system. A battery storage unit can be added to these items. Modern techniques, such as the MPPT controlling scheme, global positioning system (GPS) solar tracker, anemometer, solar irradiance sensors, and similar task-specific accessories, are available in modern PV systems for more efficient solar power extraction. Unlike traditional PV systems, CPVs have curved mirrors and optical lenses that assist irradiance onto a small but highly effective multi-junction solar cell. Because solar energy must be stored whenever it is available and the stored energy must be delivered once it is required, the installation of a storage unit is required. IoT can aid in the real-time sharing of data collected from PV sensors, as well as remote controllability of solar unit operation for failure and fault diagnosis, as well as prediction and preventative maintenance. Furthermore, grid-scale synchronization of unpredictable ESS and solar production necessitates real-time communication, which IoT infrastructure may provide. Uncertainties are largely linked to the appraisal of solar resources and the functioning of PV systems.

Monitoring the operation of the arrays is critical because it affects the PV unit's profitability as well as its dependability. In terms of income and O&M performance, identifying and responding to losses caused by a variety of factors is crucial. The performance of arrays can be measured via contracts between the PV system manufacturer, the PV owner, and the utility that guarantee the purchase of the energy produced. The intensity of solar radiation varies with time and is heavily influenced by the weather. As a result, there is no way to generate at a consistent rate. Several system components, such as the battery SOC and the voltage levels of the power converter, are affected indirectly by this issue. It is difficult for people to monitor every PV panel to prevent losses and outages, whether it is a rooftop PV system or a solar park in the desert. Additionally, frequent site visits and monitoring of operating data are necessary, which takes time when the PV facility is situated in a remote area. Human failures take a long time to address, and they are not always obvious. As a result, continuous monitoring of a real-time system that monitors parameters of the PV system and stores relevant information in a cloud-based network is necessary to be installed alongside the PV panels. The information can be utilized to gain a better understanding of the performances of PV systems and the causes of their failure. As a result, the deployment of IoT technology enables diagnosis and on-time maintenance.

3.3.3. IoT and Energy Storage Facilities

By redressing imbalances, ESS assists in boosting the dispatch capabilities of uncertain RESs. Incorporating IoT and processing a massive amount of data, on the other hand, adds a lot of complexity to the equation, but it improves autonomy. One must always strike a healthy balance between intricacy and performance (usefulness). Bulk energy time-shifting, small-scale frequency management, large-scale frequency stability, and power dependability are some of the applications of energy storage devices. Diverse energy storage systems have been developed so far for various uses. Energy storage units are critical for increasing the flexibility of power networks while also ensuring their reliability. The insecurity and intermittent nature of RESs is the key impediment to increased adoption. The use of energy storage facilities can help to decrease the danger of these uncertainties. As a result, real-time integration between these units is essential to avoid undesirable restrictions due to excess generation or detriments as a result of inadequacies. IoT infrastructure can help to make this a reality by allowing wind farms or solar parks to work together with grid-scale energy storage facilities, increasing the profitability of both types of facilities.

3.3.4. Drawbacks of IoT in Microgrid

Specific technological difficulties would need to be overcome in order to support the rapid technical development of IoT technologies as well as innovative potential application areas [167]. One of the main issues is associated with the development of different tools for the monitoring of network operations [168], then issues with security tools and their management [169], issues with software bugs, demanding maintenance of IoT networks, and finally, security issues related to IoT networks [170]. The key issue with the effective adoption of IoT technologies is related to the speed and coverage of wireless networks (Wi-Fi), where expectations are high due to both noticeable gains in Wi-Fi network coverage and increases in Wi-Fi speed over the period of 2017–2022. Globally, rises in Wi-Fi speed of more than a factor of two, or from around 24 Mbps to more than 54 Mbps, are anticipated. The Asian region is predicted to experience the greatest improvement in Wi-Fi speed [171].

4. Open Issues and Future Research Directions

IoT-based MG systems operate in a variety of situations, such as transmission line monitoring; thus, it is critical to consider aspects, such as dependability, accessibility, and compatibility with various communication technologies [172–174]. In the future, self-healing measures should be explored in conjunction with IoT technologies. If, for example, a large number of IoT devices break down, a remedial method based on self-healing capacity must be chosen, and the validity of IoT-based systems must be governed by the manufacturer. Energy acquisition, security challenges, and creating standards are also key considerations for IoT-based MG systems. Real-time power line monitoring necessitates a variety of sensors and nodes for delivering data, which is often powered by batteries. For IoT-based MG systems, most end devices are powered by batteries. As a result, obtaining power for such IoT-enabled equipment is a major outstanding question to implement such systems in the coming years. As a solution, novel energy harvesting tools in conjunction with IoT equipment must be created.

For implementing the IoT in their applications, different power supply solutions are required. Because not every power supply is suited for it, the task of designing the power supply items must also be economical, efficient, and capable of balancing heavy and light loads. Smart meters, for example, transmit a large quantity of data between the consumers and the utility. Future smart meter data flow will necessitate more sophisticated communication networks such as 5G and 6G to provide adequate wireless connectivity. Knowing the consequences prior to deployment is a critical component of this system, creating an open problem for IoT-based MG. Communication and information networking are crucial for the efficient implementation of IoT-based MG systems. As IoT MG systems evolve on various wireless networks for transferring information ranging from device scheduling to real-time EMS and power delivery, desirable and dependable network performance becomes increasingly crucial.

Expanding to modern wireless communication from 2G to 6G networks is essential for current MG structures, which will pave the way for future interdisciplinary research between electronics and electrical engineers. For such devices, different data fusion solutions are required, as they must combine data from several sources. As a result of the low processing capabilities of several IoT devices in IoT-based MG systems, storage capacity becomes a resource constraint. As a result, all of the gateways are insufficient to handle the data. Data fusion solutions for IoT-based MG systems will be a unique and innovative sector in the future for identifying the essential data from devices. Due to the different research interests on IoT [175] and MG standards, the focus on developing complete principles of IoT-based MG technologies in the future has been eliminated. The need to shift actual concentration criteria for this technology in a complementary manner is a critical open issue in the modern energy market. Data integrity [176] is becoming more important in these systems because it ensures that data collected from devices, such as smart meters, are not tampered with by unauthorized individuals.

5. Conclusions

The paper provides a brief summary of the various elements that make up a HMGS, including optimization and control topologies, as well as the problems that have to be addressed. The implementation of a decentralized power system and the smart grid paradigm was developed by the HMGS. It has many advantages over standard power networks due to its increased reliability, removal of numerous conversions, and auxiliary service. Similarly, the convergence of IoT is predicted to significantly enhance energy efficiency, functionality, and cost-effectiveness, paving the way for total automation to an IoT-based MG state. Several regulatory-based organizations and government organizations across the world have increased their focus on MGs in the electricity market in industrial, commercial, and residential buildings as a result of the creation of IoT-based regulatory standards and frameworks. Continuous regulation, including authorization based on carbon emission objectives, is required in all regions of the world, according to this remark. As a result, energy stakeholders should investigate next-generation IoT technologies in order to deal with the complexity of EMSs. As the globe proceeds toward the smart MG revolution, as addressed in this review article, there are many prospects for boosting the economy as MGs based on IoT systems face certain hurdles. Furthermore, the rapid growth of appropriate IoT designs with MGs, as well as standards, are required and will be useful in the technological arena. The operation of a HMGS depends greatly on power management strategies and control techniques, necessitating a thorough analysis of various MGs under various conditions. Additionally, it offers suggestions for future (focused) lines of inquiry in this sector.

Author Contributions: Conceptualization, S.V., V.I., B.A. and R.V.; Methodology, S.V., V.I. and B.A.; Software, S.V.; Formal Analysis, S.V., V.I. and B.A.; Investigation, S.V.; Resources, S.V. and B.A.; Data Curation, S.V., V.I. and R.V.; Writing–original draft preparation, S.V. and V.I.; Writing—reviewing and editing, S.V., V.I. and R.V.; Visualization, V.I.; Supervision, B.A. and V.I. All authors provided critical feedback and collaborated in the paper. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: Not applicable.

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

Nomenclature

AI	artificial intelligence	ANN	artificial neural network
ARCH	auto regressive conditional heteroskedasticity	ARIMA	auto regressive integrated moving average
BESS	battery energy storage system	BPNN	back-propagation neural network
CAES	compressed air energy storage	CHP	combined heat and power
COE	cost of energy	CPV	concentrator photovoltaic
DER	distributed energy resources	DG	distributed generation
DPSP	deficiency of power supply probability	DRP	demand response program
DSL	digital subscriber lines	EE	embodied energy
EMS	energy management system	ESS	energy storage system
GA	genetic algorithm	GRNN	general regression neural network
GSM	global system for mobile communication	HMGS	hybrid microgrid system
HMI	human–machine interfaces	HRES	hybrid renewable energy source
ICT	information and communication technology	IoE	Internet of Energy
IoT	Internet of Things	LAN	local area network
LCC	life cycle cost	LCOE	levelized cost of electricity
LPSP	loss of power supply probability	M2M	machine-to-machine
MG	Microgrid	MILP	mixed-integer linear programming
MPPT	maximum power point tracking	NAN	neighboring area network
O&M	operating and maintenance	PEM	point estimate method
PSO	particle swarm optimization	PV	photovoltaic
PWM	pulse width modulation	RES	renewable energy source
RSM	response surface methodology	RTU	remote terminal unit
SAPV	stand-alone PV	SCADA	supervisory control and data acquisition
SEMS	smart energy management systems	SHS	solar home system
SOC	state of charge	T & D	transmission and distribution
TCE	total cost of electricity	TCO	total cost of ownership
TS	tropical storm	VSD	variable speed drive
WAN	wide area network	WSN	wireless sensor network
WSP	wind speed prediction	WT	wind turbine

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