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Review

Implications of 5G Technology in the Management of Power Microgrids: A Review of the Literature

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Abstract: Microgrids have a lot to offer, including helping smart grids operate on distribution grids or bringing electricity to some cities. The management system receives and transmits different states. This is because the elements adapt to the conditions of the network in the shortest possible time. The 5G communication technology has high transmission speed, owing to which it can improve equipment connectivity and reduce latency, allowing the real-time analysis and monitoring of electrical microgrids considerably better than earlier generations. In addition, it is estimated that, in the near future, many cities will be connected using communication systems that allow the interconnection of different systems safeguarding the connectivity, speed, and response time of these elements in an electrical system, smart grid, or microgrids with the growing development of the Internet of Things. For this reason, it is essential to analyze the integration of 5G technology to improve the management of microgrids. This literature review analyzes and presents the advantages of using 5G technologies in reducing communication latency and improving connectivity to enhance microgrids' control and management. The active implementation of 5G in the management and control of microgrids increases the transmission and reception of data and states, reduces latency, and allows for a greater density of information, collaborating positively with resilience to the various changes that microgrids can suffer in continuous working conditions. The implementation of 5G allows electrical microgrids to be more resilient in their management and control, directly and indirectly impacting the sustainable development goals.

Keywords: microgrids; 5G technology; communication protocols; energy management; distributed systems; wireless networks

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1. Introduction

A microgrid (MG) is a system that interconnects distributed generation sources and electrical loads [1], thus optimizing power generation. It facilitates the distribution of energy to hard-to-reach places and operates isolated from the general grid so that it can continue to generate electricity even if there is a breakdown or service outage [2,3]. It is estimated that the grid will move from mass energy production to a more distributed and closer production within several years [4].

Further, MGs can be made intelligent through various control, communication, and management technologies [5,6]. The 5G is one such technology that can improve the management of MG because it has excellent connection stability and interactions with the Internet of Things (IoT), high transmission speed, and low latency [7]. In addition, the integration of IoT into 5G results in better infrastructure within MG management that helps MG to recover from different situations due to its fast transfer speed, high reliability, robust security, low power consumption, and vast connections.

The 5G technology enhances the current status of communication networks. Similar to network speed transmission, 5G is based on high radio frequencies and can significantly reduce the response time or latency between a device and the antenna [8,9]. In addition, this technology has high data transfer rates at 4000 to 5000 megabits per second, allowing it to perform some services more efficiently and in less time [10]. Therefore, it is viewed as a complementary technology that extends traditional wired infrastructure such as fiber optics [11,12].

Implementing 5G technology in MGs can regulate services between smart grids by controlling resources on demand through innovative and improved communication. In addition, this technology aids in developing and applying MGs that contribute to developing smart grids [13]. Integrating smart grids and microgrids in electrical power systems allows the development of Sustainable Development Goals (SDG7) [14], in addition to improving the adequacy of the control and communications infrastructure, achieving (SDG9) [15].

Considering those mentioned earlier, the objective of this article is to present methodological analyses of the impact of implementing 5G technologies in the management and control of MGs.

The main contributions of this paper in this field of research are:

- Literature review of the impacts of 5G technology when integrated into electrical MGs' management and control strategy.
- Analysis of the 5G technology performance compared to previous generation technologies when applied to MGs.
- Future research opportunities and gaps in the use of 5G technology for control and management of electrical MGs.

This article reviews the literature on the utilities provided by 5G technology for the real-time management of electrical MGs. With the help of information and communications technology, the 5G technology integrated with MGs minimizes latency and expands its applications. This article presents the methodology used for conducting this review and the applications of both MGs and 5G technology. We also present a discussion section where we discuss our findings and provide concluding remarks in the conclusion section.

2. Methodology

The methodology used in this study is given below:

- Search for articles: First, we performed an exhaustive search based on MG terminologies and 5G technology. The keywords were searched within titles and abstracts: MG, 5G, communication protocols, energy management, distributed systems, and wired networks. Connectors such as "AND" and "OR" were used along with the keywords to improve the search scope. Figure 1 demonstrates the results obtained using the exact keywords in different sources of information.
- Filtering of articles: After obtaining a list of studies based on keyword search, three filters were applied to retain only those studies that are relevant to the subject. The first filter used only search engines from reliable sources (IEEE, ScienceDirect, and MDPI) based on the unique and permanent identifier for electronic publications (DOI). Then, a chronological second filter was applied to the results from the first filter by selecting studies published between 2016 and 2022 because most of the research work on implementing 5G within MGs was published within this period.
- Filtering coincidences: In the last filter, the logical AND combination of the keywords shown in Figure 2 was used in the search exclusively within the title or the abstract. Accordingly, the initial search result of 26,640 was reduced to the 125 articles considered in this review.
- Analysis of results: The gaps in the research were considered as the base for this present review providing the current situation of the use of 5G within MGs.

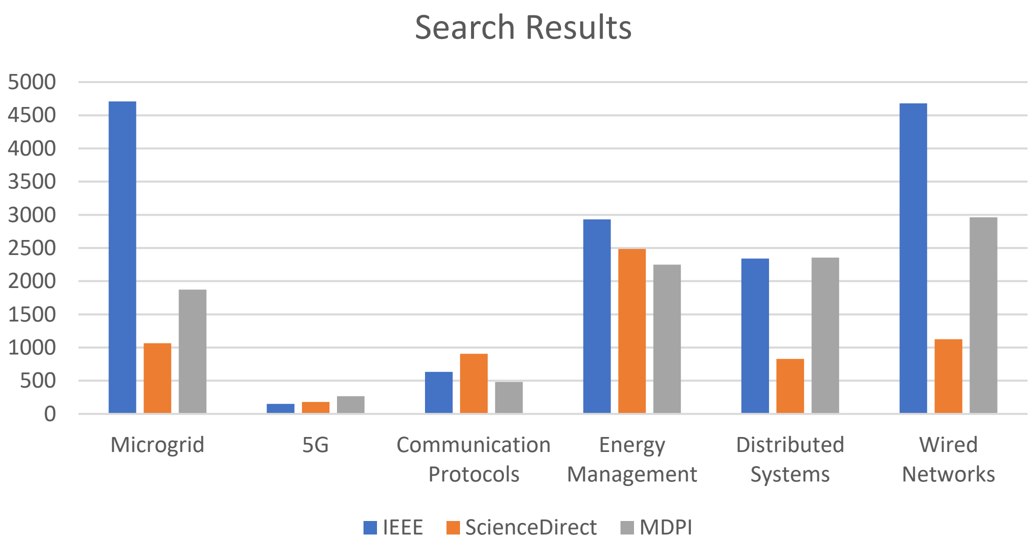

Figure 1. Search results in different sources of information.

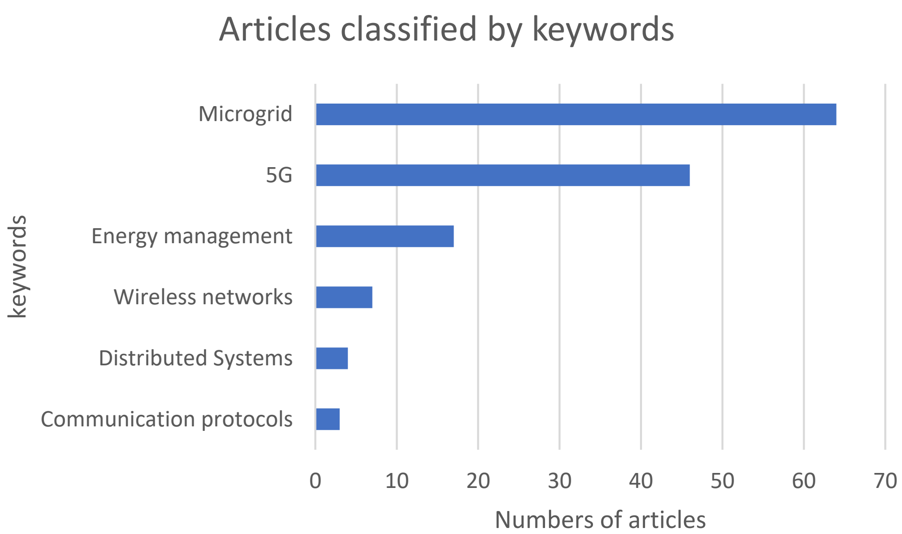

Figure 2. Filtering with keywords.

3. MGs in the Electricity Sector

An MG is an emerging small-scale energy system comprising distributed energy resources, solar photovoltaics, wind generators, microturbines, and energy storage systems [16].

Figure 3 presents the flow of energy and information in the grid and MG. Here, it should be noted that the energy flow between the MG and the power grid is bidirectional. The status elements that conform to the grid network and the MG are sent through communications systems.

Researchers have developed and revised the MGs' electrical parameters configurations [17,18].

The MGs offer many advantages, such as their ability to regulate between complementary services to the grid, automatic operation, and better quality of energy in the supply of services [19,20]. However, microgrids also have some disadvantages that should be considered as well. They are more complex protection systems, require energy to be stored in battery banks, and constantly regulate the parameters to deliver quality energy of acceptable standards [21,22].

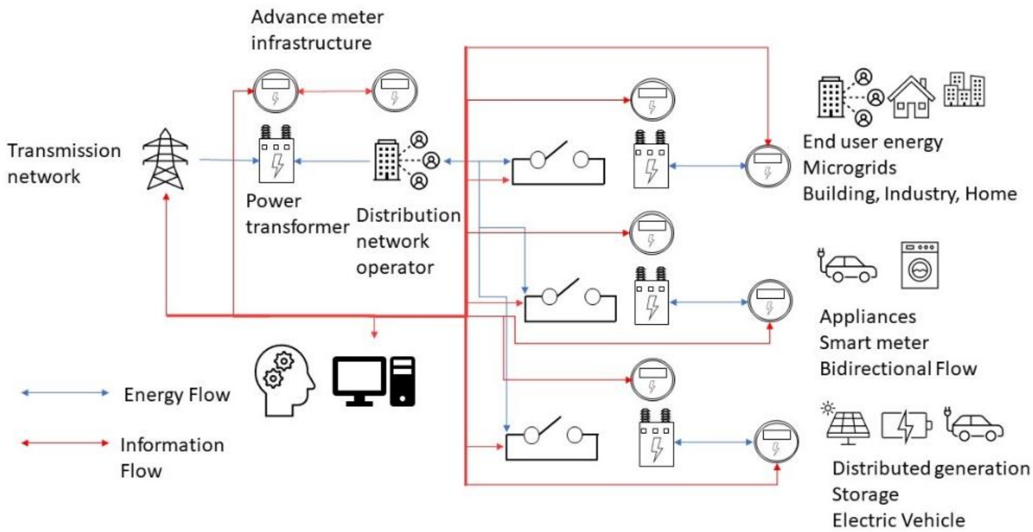

Figure 3. Flow of energy and information in the grid and microgrid.

Figure 4 compares the parameters of a conventional electrical grid and that of an MG.

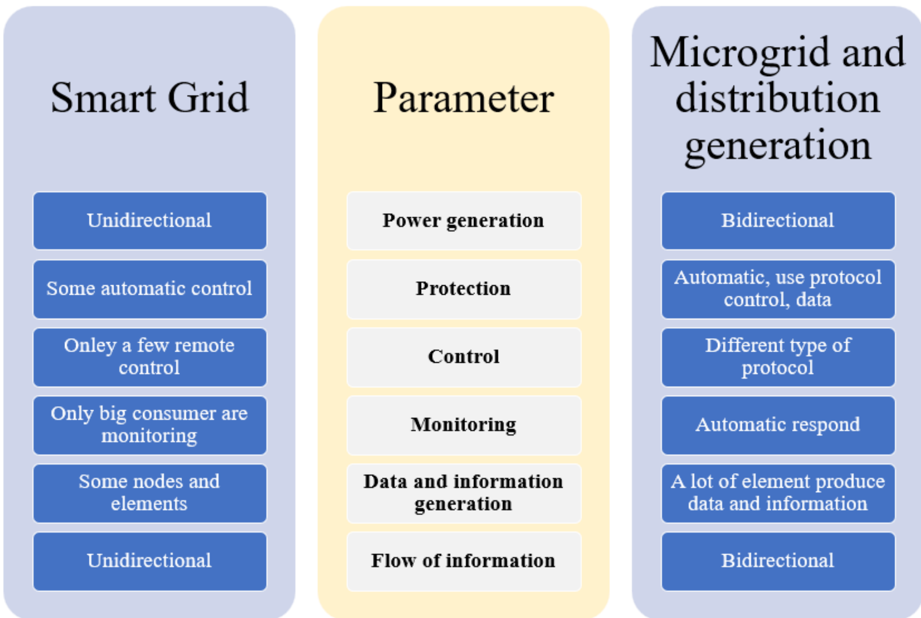

Figure 4. Comparison of communications systems in microgrids and smart grids.

Furthermore, MGs can be classified according to their focus, scope, or purpose. The configurations that can be applied in the microgrid are presented in [23,24].

Microgrid Management

An MG operation is generally flexible because it can work with the grid. It allows power supplies to be more reliable than compact systems since, in case of failures or accidents, the power levels decrease, preventing them from being completely isolated.

In addition, autonomous MGs require greater attention in operation than interconnected ones. Thus, highly efficient management is essential to obtain the best results in areas covered by autonomous MGs.

Integrating MGs into low-voltage electricity grids (conventional or smart grids) allows for better demand-side management and demand-side renewable energy resources, enabling an operation that only depends on conventional energy services.

4. MG Communications

Proper communication between all controllers can optimize the operation of the entire MG system [25]. Information and communication technologies (ICTs) facilitate the execution of MG control and protection strategies, thus enabling interoperability between the other components of the MG. The type, scalability, and interoperability of the ICT infrastructure affect the operation of an MG control system [26,27].

Data networks can be categorized into home area networks (HANs), neighborhood area networks (NANs), and wide area networks (WANs). Each network can be applied in conventional, smart, and MGs. These networks facilitate the interconnection of household appliances, smart meters, or other equipment that must be online in a communication network. NAN connects power and voltage bus substations with smart meters; in other words, the NAN interconnects several HANs. WAN interconnects several NANs and serves as interconnection points between the power control center gateway, transmission lines, power plants, and distribution network operators [28].

The size of the microgrid and the elements that conform to the MG determine the complexity of the MG. In addition, its number of nodes and the network structure's complexity will increase the communication system's data traffic [29].

The application of ICT in electricity grids enables bidirectional information and energy flows, resulting in grid-interconnected renewable energy systems [30].

Communication in MGs depends on the difficulty level of these energy systems and their requirements [31]. Nevertheless, a modern MG has a multilevel communication system that involves different factors such as operations, customers, distribution systems, transmission, market, and generation systems, as shown in Figure 5.

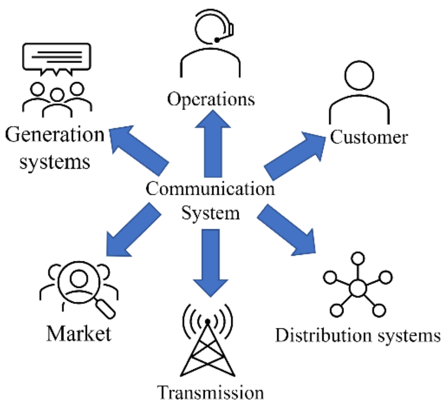

Figure 5. Modern multilevel communication microgrid.

Researchers [26,27,32–35] have shown the different applications of electrical MGs and communication systems and their respective protocols that allow interoperability between all the system elements for MGs using 5G technology. For intelligent metering, nodes within MGs use TCP-IP/NB-PLC/TCP/IP protocols. IEC 61850 standard, Modbus, or DNP3 protocols are used for microgrid control and management.

Specific fundamental points within the infrastructure of the communication system in the MG should be taken into account for their correct functioning because they have an optimal level [36]. In addition, the following aspects should also be considered:

Security: The interdependence between the electrical system and the communication network in the smart grid makes its reliability, operation, and safety issues more complex than in the traditional power grid [37]. Thus, reliability assessment studies should include the impact of communication data, as classical deterministic contingency analysis is insufficient for such assessment [38]. Some researchers have also stated the effectiveness of machine learning methods in detecting attacks with a detection accuracy greater than 95% [39].

Latency: The delay time in transmitting information in any information network is called latency. It can result in momentary or temporary loss of information within a data network. Some causes of latency include server congestion, the weight of information to be transmitted, and characteristics of the contracted internet service [40,41].

A critical requirement for touch applications in high-quality communication within MGs is low latency because it requires a low end-to-end delay in control messages [42]. The latency requirements of a communication network are determined by the selected locations of the communication entities and the implemented transmission technology [43].

Figure 6 shows that latency decreases when the technology is more updated. Therefore, the lower the latency, the more significant the number of components that can be added to the system. In addition, the decrease in latency increases data sampling, enabling the operators of the data acquisition system to respond faster in the case of protections.

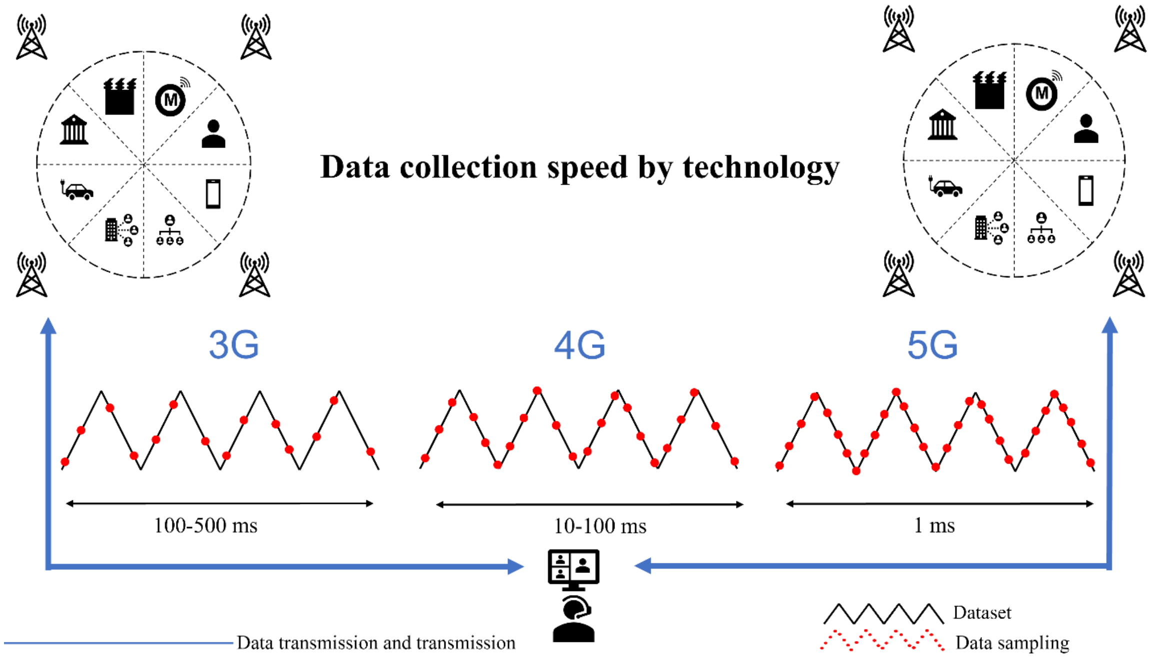

Figure 6. Data collection speed by technology.

Data delivery: MGs' power supply system operation requires high-speed data [44]. The MG control system receives and analyzes these high-speed data and then sends a control signal before the following dataset for processing [45].

Reliability: This is essential in the power supply system in MGs. This is because power converter failure can interrupt the power supply, resulting in a significant increase in the cost of system operation [46]. Thus, researchers proposed an algorithm to improve MG reliability, where the operating state of each MG can be sampled simultaneously. This algorithm also considers the interaction between various MGs in a multi-MG system [47,48].

Scalability: An essential competency of MGs is their ability to continue operating efficiently with the increased number of nodes. In some cases, the secure communication system uses a flexible control structure consisting of a local subsystem controller, a flexible controller that performs a higher level of control, and an MG central controller [49].

Broadband: MG communication involves limited bandwidth, although there is a continuous frequency of controller updates for comparisons with a feedback control over time [50]. However, when multiple levels of control are used, it may involve more significant bandwidth communication deficiencies [51].

4.1. Applications of 5G Technology in MGs

The 5G is the most advanced wireless communication technology with broad applications in smart industries, smart cities, and health [52,53]. The fifth generation of mobile networks facilitates communication with ultralow latency and high data transfer rate [54].

Many researchers worldwide are interested in the applications of 5G communication in MG technology to implement different solutions to problems in developing MGs. Table 1 presents a list of studies that propose solutions to the different adversities arising in MG technology:

Table 1. Article contributions to 5G microgrid deployments and their limitations.

References	Contributions	Limitations
[8]	This study shows the European advances in real-time measurement of phasor units incorporating smart meters.	Lack of a real-time measurement environment for slaughter units in uncontrolled conditions.
[22]	This study created isolated microgrids with a high proportion of renewable energy using 5G as communication systems.	The behavior of the system in case of being breached or in case of failure.
[55]	This study shows the advances in two-way demand and response services in Korea.	Lack of implementation of blockchain for energy trading through operations systems management.
[56]	This study shows the advances in the distributed control and monitoring of decentralized renewable energy sources in Germany.	Consideration of microservices within the proposed platform for the multi-microgrid.
[57]	This study presents the implementation of renewable energies with 5G in isolated microgrids.	The behavior of load frequency control in systems with multiple power sources in maritime microgrids.
[58]	This study shows the progress in implementing different communication protocols for microgrid protection using 5G.	Field studies for the implementation of adaptive protection through wireless communications.
[59]	This study presents a predictive control model of a power buffer to stabilize DC microgrids in the case of delayed nonlinear networks.	Soft materials used compared to decentralized drop control for DC microgrids.
[60]	This study offers a ready-made plan in India to predict and schedule transactions between electric power prosumers using electric vehicles having 5G.	Operation in remote areas with little network access continuously.
[61]	In Finland, 5G nMTC and uRLLC are used in microgrids to control machines with low latency remotely.	Analysis of what is proposed for other types of regions with different conditions of the electricity sector.

The new generation of communication networks has several features, such as data transfer of 1–10 gigabits per second (Gbps), high bandwidth, ultralow latency, reliable connection between devices, mass communication between machines, high energy efficiency, simultaneous redundancy, and a prosumer [62]. Figure 6 presents a comparison of three types of networks.

Figure 7 shows that all technologies have "scalability", which refers to the ability of networks to increase in size when the number of nodes increases, and its reaction to the constant increase in workflow [63].

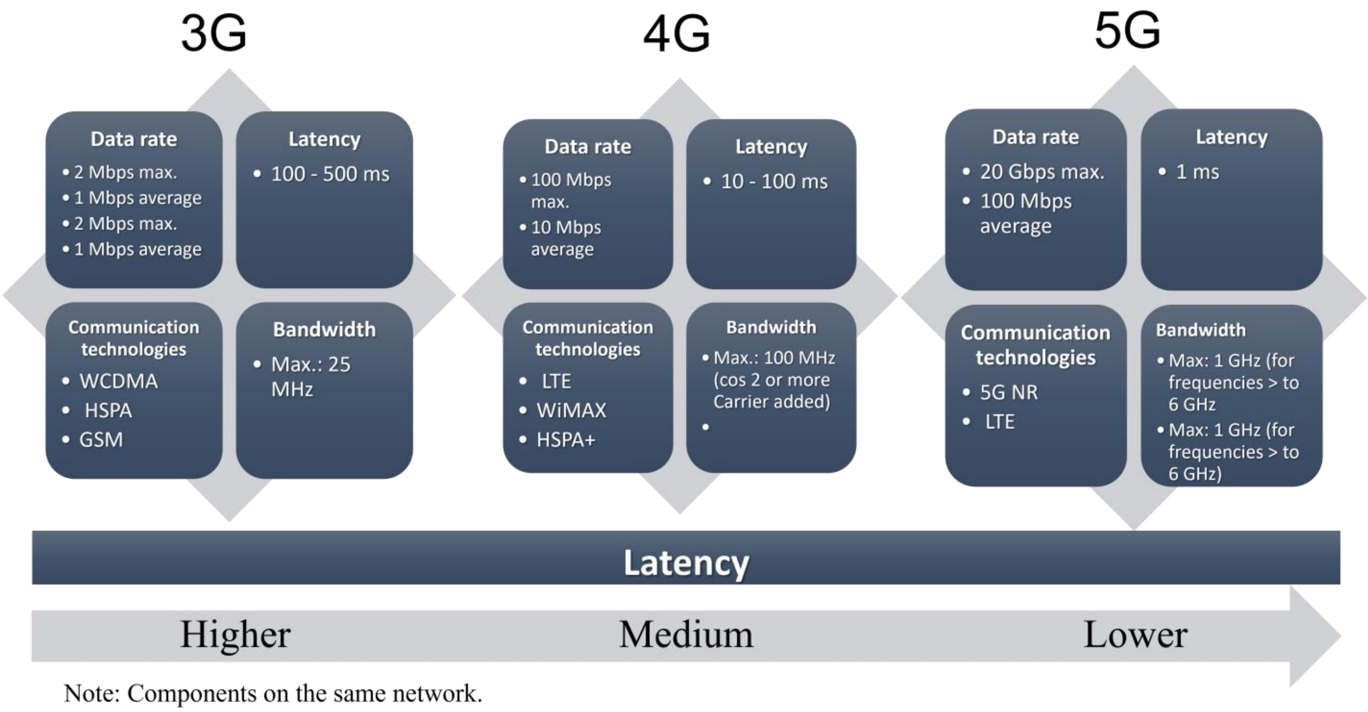

Figure 7. Comparison of network groups.

Compared to previous technologies transmitted by long-distance antennas, 5G is transmitted using many small antennas placed on the roofs of buildings or light poles because of the frequency spectrum in which they travel [64].

The 5G technology has many advantages, including higher data transfer speed, IoT-enabled technology, and energy consumption savings of up to 90% [65]. However, its disadvantages include its low capacity to cross obstacles, limited availability of 5G-compatible devices in the market, and expensive spectrum bands of the network [66].

The development of 5G technology provides a broader basis for the energy system, such as bilateral energy business, dynamic energy pricing, and active wireless transmission spectra between the MG and the network [67,68].

The 5G technology is being increasingly used in energy systems [69]. It can incorporate the following business needs depending on the performance characteristics [70]:

- Intelligent power distribution automation to obtain coordinated and automated system protection control.
- Collection of low-voltage power information, charging station/smart car battery, and distribution of crucial terminal access requirements for uplink services of information collection type, such as access to the power supply.
- Monitoring the status of power transmission and distribution systems, video calls, high-definition return phones, an electrical system inspection through remote supervision, and emergency communication.
- Millisecond-precision load control detects faults in the electrical network in real time, integrates various types of power supplies, and performs coordinated control of all equipment in the network.
- It ensures the reliability of differential protections and low latency of the active distribution network to protect industrial control downlink services.

4.2. MG Configurations with 5G Technologies

Traditionally, MG configuration involves determining the optimal configuration of system power, type, and size of installed generators to meet load requirements at a minimal cost. An essential aspect of the MG planning and design stage is configuring distributed generation capacity [71]. In order to meet the diverse needs of users and cover unexpected events, and ensure system reliability, devices must be reasonably configured [72]. MGs can be optimally configured using optimizers based on models proposed according to requirements [73].

Hybrid algorithms have been developed to create optimal reconfiguration of grids in the distribution network in the presence of distributed generation resources [74]. In a hybrid algorithm, the generation node and the load node interact in real time and can assist in dynamic system modeling to minimize performance losses in the network [75].

At the time of configuration, the type of MG energy production should be considered due to the uncertainties associated with renewables, especially for what should be considered during the MG planning period [76]. Power electronics are sometimes integrated with 5Gs to have fewer functional transmissions, permanently creating a sleep time of less than 1 ms and reducing latency and power consumption. It is also used to facilitate the distribution within MGs. Table 2 presents an example of a microgrids use 5G for control, and Table 3 presents microgrids use 5G management applications.

Table 2. Some microgrids use 5G for control.

Ref.	Objectives	Protocols	Uses of 5G	Contributions	Limitations
[77]	Presents different cases of prevention and reaction to optical network disasters to increase the facilities' resilience and maintenance of the services.	Deployment of recovery nodes to avoid traffic affected by disasters through wireless backhaul based on disaster risks of the possible optical nodes.	It is expressed by its advantages of excellent data transmission and low latency for the early arrest of alerts or possible warnings of adversity.	They include preparedness plans for different disasters and reactive procedures that allow effective implementation of post-disaster recovery operations.	A large part of the stipulated proposals must be implemented from the planning side, making it challenging to implement in operational facilities.
[78]	It seeks to efficiently present a novel methodology for developing integrated 5G thermal, electrical, and mobility networks.	It is not specified.	It is intended to use 5G with the help of techniques by connecting flexible electricity demands and electric vehicles with intermittent power sources such as renewables and storage using artificial intelligence to facilitate optimal control to manage carbon footprint.	It shows the implementation of the 5G concept due to costs within the energy domain, reducing costs for consumers and transforming an existing urban area into a near-zero carbon energy system in terms of heating, cooling, electricity, and transportation.	The energy transition wants consumers to commit to active participation in demand-side response, so the way and timing of the energy used must be changed.
[79]	Present the strengths and possible implementations of artificial intelligence in the collective behaviors of simple agents with limited capabilities seeking to achieve intelligent strategies to solve large-scale problems.	The paper discusses protocols focused on routing mechanisms in wireless sensor networks and ad hoc vehicle networks.	5G is introduced as enhanced mobile broadband, massive Internet of Things, and ultrareliable, low-latency communication.	It includes topics aimed at swarm intelligence and presents optimization tools for wireless networks, touching critical points for its implementation.	The correct way to reduce the search space size and the ability to find the optimal solution globally is unknown. In addition, the implementation under different scenarios is incompatible with those expressed in the job.

Table 2. *Cont.*

Ref.	Objectives	Protocols	Uses of 5G	Contributions	Limitations
[80]	It is expected to demonstrate how to design a green building with energy-saving measures aided by 5G technology.	Two protocols are Transmission Control Protocol and User Datagram Protocol.	5G networks are proposed to accelerate data transmission for smart device connectivity, the rapid response to growing trends in green building design.	It presents methods for designing green buildings with energy-saving measures to minimize the impact of energy consumption and extract information from residential buildings through simple, low-cost sensors.	Lack of work or implementation of pilot programs to monitor data in a natural or poorly controlled environment is proposed.
[61]	A comprehensive review of cybersecurity, consumer privacy, and disaster recovery reliability is presented, focusing on demand response with the help of 5G.	Unspecified.	It is pursued that the emerging 5G technology and the Internet of Things can provide better infrastructure for disaster recovery due to fast transfer speed, high reliability, and a large number of connections.	It presents essential features and application scenarios typical of 5G communication and contemplates demand response before 5G technology enters the large-scale commercial stage.	It does not contemplate implementing the proposed model to existing or operational smart grids.
[59]	Predictive control synthesis of the fuzzy model of a power buffer for dynamic stabilization of a microgrid controlled through a low-latency communication network.	The study discusses network-based call signal protocols for data packets based on transmission time.	With the help of 5G, many of the critical requirements of the power grid can be met because it is a cost-effective alternative to new fiber, which is expensive to implement.	A fuzzy observer and model prediction scheme alleviates the effects of 5G-induced delays and data loss from sensor-to-controller and controller-to-actuator links on a microgrid's DC plant response.	The system is not intended for centralized energy systems and cannot be applied in all cases.
[57]	It presents the applicability of future 5G grid technology for a marine vessel power system with ocean wave power, photovoltaics, and energy storage systems.	It talks about specific protocols such as Can bus, Ethernet, ZigBee (IEEE 802.15.4), WiMax (IEEE 802.16), and Wi-Fi (IEEE 802.11).	5G network technology is used as communication infrastructure in the proposed model.	It presents an exciting approach to using 5G for a marine vessel power system with sea wave power, a controller-based photovoltaic, and an energy storage system for the secondary load frequency of a network of multiple microgrids on board.	There are few details of the pilot plant in the document.
[77]	Presents different cases of prevention and reaction to optical network disasters to increase the facilities' resilience and maintenance of the services.	Deployment of recovery nodes to avoid traffic affected by disasters through wireless backhaul based on disaster risks of the possible optical nodes.	It is expressed by its advantages of excellent data transmission and low latency for the early arrest of alerts or possible warnings of adversity.	They include preparedness plans for different disasters and reactive procedures that allow effective implementation of post-disaster recovery operations.	A large part of the stipulated proposals must be implemented from the planning side, making it challenging to implement in operational facilities.

Table 3. Some microgrids use 5G management applications.

Ref.	Objectives	Protocols	Uses of 5G	Contributions	Limitations
[81]	Power small-cell base stations into an ultradense 5G network infrastructure to reduce power supplies from the power grid.	Modern backhaul protocols are used to forward backhaul traffic energy-efficiently at these facilities.	5G in small-cell cellular base station installations form small-cell networks using spectrum reuse policy to meet growing demand.	An efficient alternative to energy consumption within the infrastructures necessary for the 5G network with the help of renewable energies.	Lack of adequately defined protocols for this type of facility.
[82]	It is intended to minimize the delay time with minimum installation cost, focusing on renewable energy networks.	ZigBee protocol is used for pole-to-pole communication and maximum data rate.	Data transmission for analysis and decision-making is transmitted through 5G-enabled towers.	It features a wireless network for real-time monitoring of transmission lines to take preventive measures using 5G technologies.	Access to the network and the location of transmission towers enabled cell phones.

Table 3. *Cont.*

Ref.	Objectives	Protocols	Uses of 5G	Contributions	Limitations
[83]	Build an energy network through a packaged load management contemplating the cyberphysical implementation of energy packets, where user requests are stipulated to be sent to a powerful server.	A particular protocol is proposed for the efficient transmission and adaptation of the parts to the purpose. It is specified that subscribers are matched with demand providers, and then routers help transmit power through their different channels.	5G is expected to be used as the effective enabler of machine-like communications that includes a wide range of heterogeneous applications with different requirements.	It envisages an approach to power grid management based on cyberphysical power packets where users are prosumers within the microgrid and have a commonly managed inventory.	It lacks a series of configuration case studies to analyze data in an uncontrolled environment.
[84]	It stipulates an energy-saving system based on digital twins for the industry and analyzes the importance of the relationship necessary for an energy-saving industry based on digital twins.	It is claimed that SCADA is used with the Modbus RTU protocol.	The standardization of the Internet of Things, artificial intelligence with 5G, and blockchain 3.0 within the industry based on digital twins are expected.	It presents the current approach to saving industrial energy with cutting-edge technologies for Industry 4.0. It also proposes standardizing and modularizing the industrial data infrastructure for intelligent energy-saving.	Close communication and collaboration between academicians, industrialists, and policymakers are required to implement such projects properly.
[85]	It considers the energy used in the design of future mobile networks and proposes to use HD energy harvesting hardware to reduce the environmental footprint of 5G technology.	It mentions a protocol called harvest-then-transmit.	Current trends are 5G mobile networks, especially those composed of ultradense deployments of heterogeneous base stations.	It presents proposals to make the most of the energy collected, especially from renewable energy, while meeting the quality of service required by dense 5G deployments.	At work, situations with nonoptimal energy supply are not considered energy storage tools.
[86]	Presents a brief overview of the architecture of an intelligent city system introducing the application, detection, communication, data, and security/privacy blueprints.	Different protocols include message queuing telemetry transport, extensible messaging and presence protocol, and advanced message queuing protocol, among others.	They opted for 5G because it avoids already congested microwave bands and paves the way to support substantially higher data speeds and a more significant number of connections.	It presents the adaptation of existing communication protocols and infrastructures to bring together massively deployed sensors and communication data storage/processing resources unique to smart cities.	A different process is required to specify security and resilience in each case effectively and requires a personalized treatment regarding data privacy.
[87]	Make the most of renewable energy by combining developed self-powered sensor nodes, self-sustaining wireless sensor nodes, and self-charging energy storage units.	The use of ZigBee protocol (IEEE 802.15.4) is contemplated.	The rise of endpoints, such as 5G base stations, will reinforce the concept of the Internet of Things, especially those with wireless data communication devices.	It contributes to the efficient use of electrical energy in smart cities and seeks to strengthen it by increasing 5G endpoints and accelerating digitalization in smart cities.	It does not contemplate a reaction in response to a security attack or an external favor than expected.
[88]	A systematic review of 5G failures of leading research databases and cutting-edge research articles to create a comprehensive classification framework on relevant requirements.	A trend is seen in the paper in protocols such as IEEE 1451 for intelligent transducer interface standards, the IEEE 1815 standard for electrical power system communications—DNP3, and IEEE C37.238.	It states that 5G replaces optical communication links to achieve greater flexibility, reliability, and cost savings. In addition, 5G paves the way for broader integration of renewable energy sources into the electric power grid.	The document includes in detail the classification of different failure scenarios into a comprehensive framework involving the application level of the system.	It does not contemplate possible solutions or actions to follow based on the defects of the review.

4.3. Implementation Cases

In some cases, the researchers briefly explained the research on 5G implementation in MG technology. These research works served as pilot schemes for this study.

- **Renewable Energies**

Facilities need to be expanded, and power generation efficiency needs to improve to increase the participation of renewable energy technology in the power system. The abovementioned can be achieved by operating and managing existing facilities. These problems can be solved by integrated control and management of new and renewable power generation facilities using the Internet of Energy. The necessary energy capacity using renewable energy can be maintained using fault detection technologies with remote monitoring. The above also allows renewable energy maintenance of the necessary energy capacity [55].

- **Energy Storage System**

The energy storage system was built based on the energy management of buildings and industries, where standardization works as peak control, renewable energy stabilization, frequency adjustment, and grid control [56].

- **Electric Vehicle Charging**

The 5G networks and the standard hierarchical architecture facilitate using distributed energy resources (micro- or nanogrids, vehicles, and others). The previous can lead to an optimal transaction between consumer and producer using lightweight, low-latency communication protocols. In this way, users can adopt the position of consumers and producers [89].

- **Teleprotection electrical systems**

Coordination of protections is critical in the grid, smart grid, and MGs. In addition, communications systems allow sending and receiving information with the lowest possible latency and in the shortest time, achieving correct coordination between the elements of protection in the grid [58]. There is a demand for a real-time data exchange that can only be achieved using new communications networks by integrating intelligent electronic devices, IoT equipment, smart metering, teleprotections, and grid controllers [90].

5. Discussion

The use of 5G technologies in MGs is associated with a decrease in latency and lower power consumption, offering excellent connectivity between devices, among other things. This technology positively impacts the management of electrical MGs as it improves their efficiency and allows real-time monitoring and control. However, the investment and maintenance costs are very high for this system, which is only for the management part with 5G technology.

The 5G technology brings significant changes in the digital space and positively impacts smart cities. It increases the development and implementation of smart cities, improving data transfer speeds and reducing the response time of systems. It allows the creation of resilient electrical systems proposed by the sustainable development objectives.

Shortly, 5G technology will become the basis of digital and industrial transformation. However, to efficiently utilize this technology, cities must improve in other aspects, such as technology and their policies on their ecosystem and business, due to the high investment cost of this system.

In today's scenario, only a handful of countries can integrate or develop an MG with renewable generation systems and 5G technologies. This is because of the limitations associated with 5G technology. These limitations include the cost of 5G infrastructure, deployment of fiber optics for data transport, radio spectrum management, and energy backup systems.

However, the 5G mobile network shows a significant advantage over previous technologies because of its high transfer speed, low latency, and higher bandwidth. These features allow the better management of renewable and nonrenewable energy resources and the interconnected demand of the MG. In addition, the speed in communications is essential in teleprotection, especially in the differential of lines. Generally, a trip transferred from one substation to another must arrive in 4 ms. Therefore, in some cases, the current measurements of these substations are connected by fiber optics. However, the use of 5G in these cases can not only achieve the required level but also save the fibers.

As shown in Figure 8, different researchers proposed the integration of 5G together with smart cities, MGs, and industry. In the case of smart cities, the integration system is proposed to be under constant monitoring of the use of electricity by the end user in real time. It can be achieved by using smart meters with free access to this consumption for both the distributor and users, regardless of the type of services they consume.

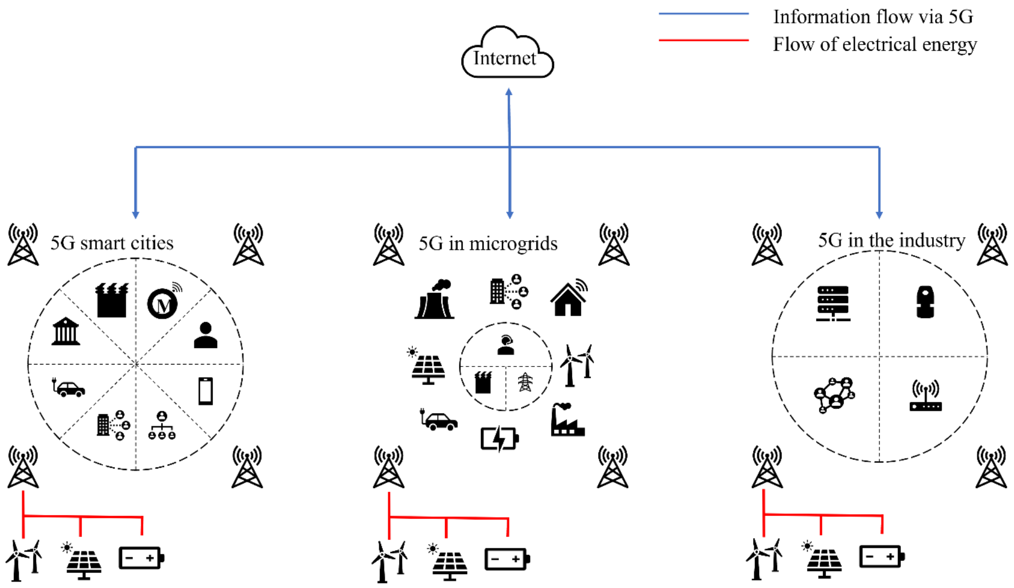

Figure 8. 5G applications within the microgrid.

The use of intelligent sensors is stipulated within the production processes to have precise control over a situation; the control center acts, while application servers control the actuators of the different stages of production. This solution facilitated dynamic changes with a shorter downtime for changes. Thanks to its low latency, reference is made to the integration of 5G as a data transport route.

In the case of MGs, the use of technologies provided by 5G proposed continuous network analysis. Accordingly, consumption and demand could be actively analyzed, giving way to an acceptable response time to network changes. In another vein, some researchers refer to this as conferring additional resilience, creating a new layer of security against possible attacks or eventualities within the MG, regardless of its nature. Although cybersecurity would pose a considerable challenge to the successful implementation of 5G technologies, further research must also be conducted.

Integrating 5G technology within these systems requires base stations with a large electrical energy consumption. Therefore, some researchers proposed using alternative energies to be more environmentally friendly. Figure 8 refers to using renewable energy to power these base stations, considering wind energy, photovoltaics, and a good storage system.

As shown in Figure 9, a conglomerate of TCP/IP model protocols is categorized based on their application layer. These protocols have different applications depending on their applicability. Each of them are communications protocols focused on controlling and monitoring MGs.

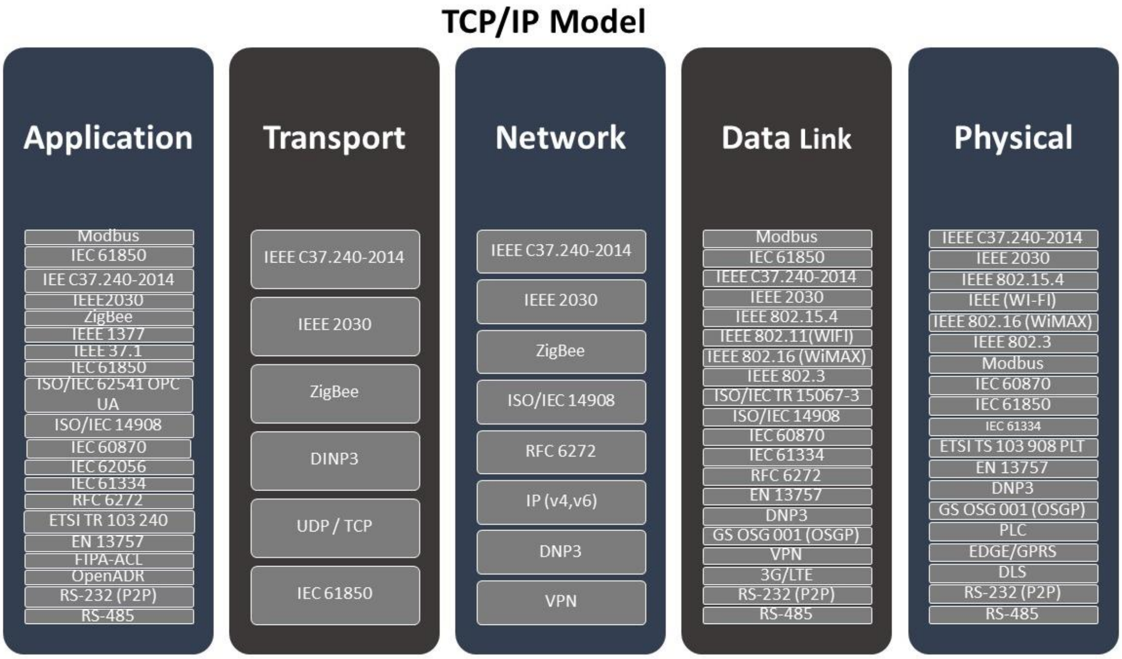

Figure 9. Communication protocols based on TCP/IP model.

6. Conclusions

This review examines the status of MG deployment alongside 5G technology and explores its use in renewable resource management and interconnected energy demand. The findings of this study will allow other interested researchers or readers to expand their knowledge on this topic and will provide different projects carried out in other countries.

At present, MGs are being integrated into interconnected systems. Therefore, the response of the MG must be in real time to determine the exact demand for decision making and actions; thus, 5G can effectively collaborate in managing them.

Through regulatory bodies, countries must begin to utilize 5G technology efficiently. When the necessary resources are available, researchers and organizations will soon start generating projects for field studies or start-up experiments in real MGs.

A literature review showed that different authors referred to using renewable energies to power the stations necessary for implementing 5G. It indicates that they propose using renewable energies to reduce carbon footprint as these facilities demand very high energy. It also allows greater penetration of distributed generation, smart grids, and microgrids in power systems since management, control, and teleprotection will have a reduced delay time, allowing it to be the most resilient power system and reach SDGs 7 and 9.

It should be noted that there is a lack of sufficient literature on the subject, indicating the lack of exploration on this topic and limited field studies, as it is a recently developed field. That is why there is motivation to investigate the creation of knowledge, although it is true that it is a new field in development with great strengths that position it as an emerging promise in the use of MG management.

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Abbreviations

MG	Microgrid
USDOE	US Division of Energy
LAN	Local Area Network
WAN	Wide Area Network
EMS	Energy Management Systems
PI	Proportional–integral controllers
ANFIS	Neuro-diffuse adaptive inference system
DMS	Demand management system
DR	Demand response
AMI	Advance Meter Infrastructure
MDM	Meter Data Management
PMU	Phasor units of measurement
ESS	Energy storage system
ULL	Ultralow latency
IoE	Internet of Energy
ICT	Information and communication technologies
SCADA	Supervisory control and data acquisition
MQTT	Message Queuing Telemetry Transport
XMPP	Extensible messaging and presence protocol
AMQP	Advanced Message Queuing Protocol
TCP	Transmission Control Protocol
UDP	User Datagram Protocol
DSRC	Dedicated short-range communications
NCS	Network-based call signal

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