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# Microgrid Based on IoT Systems: An Overview

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***Abstract**: As the cornerstones of the smart grid of the future, smart microgrids integrate various Internet of Things (IoT) designs and technologies for applications intended to establish, manage, keep an eye on, and safeguard the microgrid (MG), especially as the IoT grows and changes every day. Urban and rural communities, as well as institutional, commercial, and industrial users, find a smart microgrid (MG) to be a perfect solution. It is a tiny grid that can function independently or in conjunction with the power grid. A MG has two modes of operation: stand-alone and grid-connected. It can switch between these modes in response to various circumstances, such as planned maintenance, expansions, local grid faults, host system deficiencies and failures, and so on. 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.*

***Keywords:** Iinternet of things; smart microgrid; cost of electricity; information and communication technology*

## 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].

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.

The islanding detection techniques are normally classified in to local and remote techniques. Remote techniques are communication-based techniques which employs power line signaling scheme [4]-[5] or supervisory control and data acquisition (SCADA) for detection of island [6]. These methods have negligible NDZ and are reliable as compared to local methods but they are uneconomical for implementation in small distribution system.

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. Fig. 1 show sample of microgrid.

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 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 1 shows the primary capabilities of a MG.

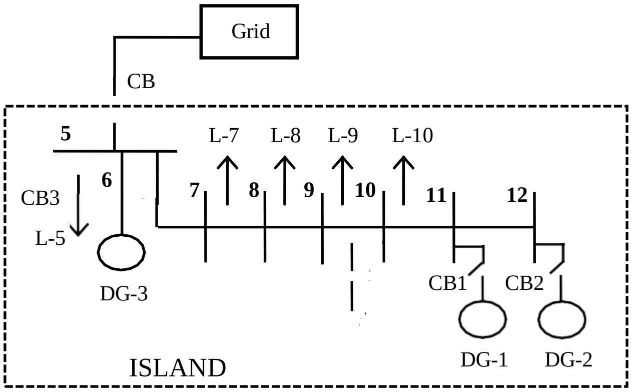
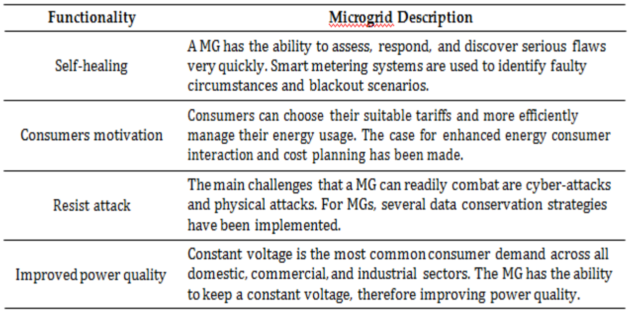


Fig.1. Sample microgrid model

**Table 1.** 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.

## 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 [20-22].

### *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].

## 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 eco- nomic 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 DC MG* Thousands

The following are the shortcomings of the forecasting strategies:

1. 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 method- ologies 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.

Despite the usage of alternative methods, AI technologies were thoroughly investigated and are now being utilized to handle complex relationships and make ac- curate assumptions. These techniques can be used to capture the actual series in non-linear patterns.

## 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 [52]. 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 [53] 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 2, 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.

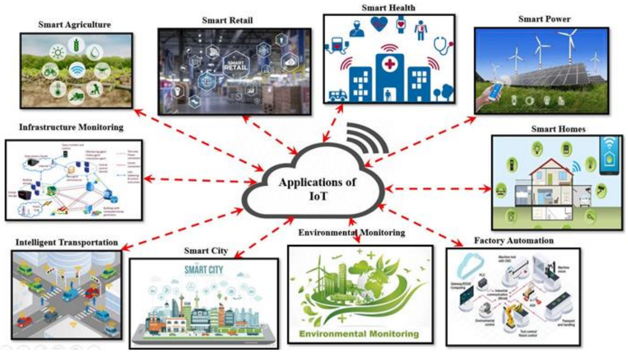


Figure 2. IoT in the real world

As per a Forbes survey [53-60], leading brand businesses are expected to sell over 411 million wearables on the digital market by 2020. In article [61-65], 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 [66-70] 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 [71-78], progressive software resources, and enhanced sensors, Industrial IoT has the potential to empower whole sectors. Figure 3 shows that the majority of the market is focused on smart cities and industrial IoT.

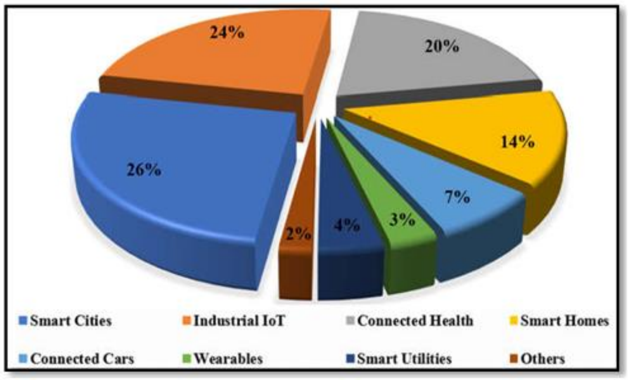


Figure 3. General market structure of IoT technologies [79].

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 [80-89]. 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 health- care, 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.

## 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 [90-100], 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. 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 [101] and Sigfox [102], 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 [103-108] and establishing a network structure with cloud-based application areas.

## 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 [109]. 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.

## 3.4 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 re- sources. 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 [109], which represents the net present value of the unit–cost of power throughout the turbine's lifespan.

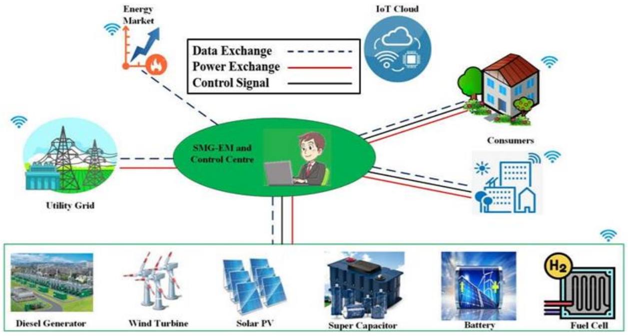


Figure 4. IoT-based optimal energy management and control for a MG.

## 3.4 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.

### 3.5 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.

### 3.6 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. One of the main issues is associated with the development of different tools for the monitoring of network operations, then issues with security tools and their manage, issues with software bugs, demanding maintenance of IoT networks, and finally, security issues related to IoT networks. 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 [110].

## 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 [111–112]. 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 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 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. Conclusion

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.

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