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Distributed generation for Microgrid technology

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Abstract

Distributed Generation (DG) refers to the generation of electricity from various small-scale sources of energy such as solar panels, wind turbines, or micro-turbines, located near the consumers. Microgrids (MGs), on the other hand are localized and autonomous electrical systems that can operate independently or in connection with the main power grid. The integration of DG within MGs has gained significant attention due to its potential benefits. This arrangement allows for increased efficiency, improved reliability, and enhanced resilience in the delivery of electricity. Furthermore, it enables the utilization of Renewable Energy Sources (RESs), reducing reliance on conventional fossil fuel-based power generation. In an MG with DG, the power generation sources are dispersed throughout the grid, supplying electricity to nearby consumers. Depending on the availability and generation capacity of each source, the MG can efficiently balance the energy supply and demand. In cases where excess generation occurs, the surplus energy can be exported back to the primary grid or stored for future use. The decentralized nature of distributed generation in MGs also contributes to more excellent grid stability and reliability. If any part of the main grid experiences a power outage, the MG can continue to operate independently, providing uninterrupted electricity to the connected consumers. This feature is especially valuable in remote areas, critical facilities, or during emergencies, where maintaining a reliable power supply is essential.

Keywords: DG; MG; RESs; Conventional fossil fuel

1 Introduction

A number of small-scale power sources positioned close to the point of consumption are referred to as Distributed Generation (DG) [1]. These sources can include renewable energy systems, such as solar panels, wind turbines, and small-scale hydroelectric generators, as well as conventional fossil fuel-based generators [2]. MicrogridS, on the other hand, are localized power systems that can operate either independently or in conjunction with the main grid [3], [4]. They incorporate various Distributed Energy Resources (DERs) and are capable of generating, storing, and managing electricity within a localized area [5]. The introduction of distributed generation into microgrids brings several benefits. Firstly, it enhances the overall resilience and reliability of the electricity supply [6]. By having multiple smaller power sources spread across the microgrid, any failures or outages in one source can be compensated for by others [7]. This decentralized approach reduces the vulnerability of the microgrid to single points of failure, improving its reliability [8]. Secondly, distributed generation in microgrids enables better integration of renewable energy sources [9]. Renewable energy systems like solar and wind often face intermittency issues due to weather conditions [10].

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By dispersing multiple renewable generation sources within the microgrid, the overall electricity supply becomes more stable and sustainable [11]. Moreover, distributed generation in microgrids can lead to improved energy efficiency. It reduces line losses by minimizing the need for long-distance transmission of electricity [12]. Local generation closer to the point of consumption results in lesser energy wasted during transmission [6]. Lastly, DG in microgrids offers increased control and flexibility in managing energy supply and demand [9]. With advanced monitoring and control systems, microgrid operators can optimize the use of distributed generation resources, store excess energy when demand is low, and meet peak demand efficiently. Moreover, the incorporation of distributed generation into microgrids promotes a more resilient, sustainable, and efficient energy supply system at the local level [2]. Furthermore, the integration of DG within microgrids offers numerous advantages including improved efficiency, utilization of RES, enhanced reliability, and increased resilience [2]. This innovative approach to energy systems holds considerable promise for a sustainable and reliable future power infrastructure [1].

The contribution of this article is providing the technologies and integrated application of MG to more excellent grid stability and reliability. The rest of the article is organized as follows. The methods and materials for most widely utilized RESs are presented in Section 2. The types of renewable energy sources along with their further details are described in Section 3. Section 4 comprehensively discusses the MG applications along with their features. Detailed discussion on the MG technology along with their merits and demerits are discussed in Section 5. Eventually, the conclusion and references are closing the article.

2 Material and methods

Various RESs are forms of energy that can be replenished naturally within a human lifetime and do not deplete the Earth's resources [1]. Some of the commonly classified RESs are figure out in Figure 1 and further explained in Table 1. These RESs offer several environmental benefits, including lower greenhouse gas emissions and reduced dependence on fossil fuels [13]. However, each source has its unique characteristics and requirements for effective implementation [14].

Table 1 Classification Renewable Energy Sources [12], [19]–[24]

List of RESs	Remarks	Form
Solar Energy	Solar power harnesses the energy from the sun through technologies like photovoltaic (PV) cells or solar thermal systems Converting sunlight into electricity or heat.	
Wind Energy	Wind turbines capture the kinetic energy of the wind and convert it to electricity. As wind blows, it spins the turbine's blades, generating power.	
Hydroelectric Power	Hydroelectric plants generate electricity by harnessing the energy of flowing or falling water, such as rivers or waterfalls. Water drives turbines, producing electricity as it moves.	
Geothermal Energy	Geothermal power utilizes the heat from the Earth's core. It involves tapping into underground reservoirs of hot water or steam to generate electricity or provide heating and cooling.	

Biomass	Biomass energy is derived from organic materials like agricultural waste, wood pellets, or dedicated energy crops. It can be burned to produce heat or converted into biofuels for transportation and electricity generation.	
Tidal and Wave Energy	Tidal and wave energies capture the kinetic energy of the ocean's tides and waves, respectively. Convert it into electricity through devices like tidal turbines or wave energy converters.	

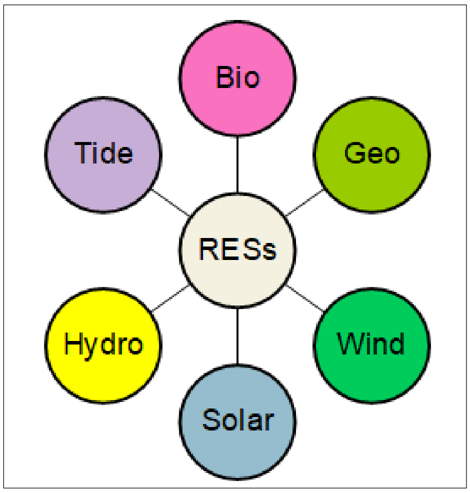

Figure 1 Classifications of Renewable Energy Sources [15]–[18]

2.1 Classification of Renewable Energy Sources

Renewable energy sources refer to those energy resources that can be replenished naturally over a short period of time [25]. The selection of materials and methods for renewable energy depends on the specific type of energy source [26]. Some common RESs along with their material and methods are tabulated in Table 2 [27]–[29]. Each energy source has its own specific requirements and technologies, and ongoing research aims to improve efficiency and explore new possibilities in the renewable energy sector.

Table 2 RESs methods and materials [30]–[32]

RESs	**Materials**	**Methods**
Solar Energy	Solar panels, photovoltaic cells, inverters, batteries	Solar panels capture sunlight and convert it into electricity using photovoltaic cells. Inverters convert the direct current (DC) produced by solar panels into alternating current (AC) usable in homes and businesses. Batteries store excess energy for later use.
Wind Energy	Wind turbines, rotor blades, gears, generators	Wind turbines harness the power of wind to generate electricity. The rotor blades, driven by the wind, spin the generator, which produces electricity through electromagnetic induction. Gear systems help the rotor blades optimize wind energy conversion.
Hydropower	Dams, turbines, generators, penstocks	Hydropower utilizes the energy of moving water to generate electricity. Dams store water in reservoirs, which is then released to flow through turbines. Turbines spin generators to produce electricity. Penstocks control water flow and pressure.

Biomass Energy	Organic waste, crops, wood chips, agricultural residues	Biomass energy involves the conversion of organic matter into usable energy. This can be achieved through combustion, gasification, or anaerobic digestion processes. Biomass is burned to produce heat or converted into biogas, biofuels, or electricity.
Geothermal Energy	Heat pumps, geothermal power plants	Geothermal energy utilizes the natural heat from within the Earth's crust. Heat pumps extract heat from shallow ground or bodies of water, heating or cooling buildings. Geothermal power plants tap into naturally occurring underground heat reservoirs to produce electricity.

2.2 Application of MG

Microgrids have various engineering applications across different sectors as presented in Table 3. Besides, microgrids provide flexibility, reliability, and sustainability in engineering applications, offering a potential solution to various energy challenges in different sectors.

Table 3 Microgrid application

List of applications	Features	Ref
Renewable Energy Integration	Microgrids can efficiently integrate RESs such as solar panels and wind turbines into the power distribution system. By managing the intermittency and variability of these sources, microgrids contribute to a more reliable and sustainable energy supply.	[33]
Remote and Island Communities	Microgrids are particularly valuable for remote areas or islands where access to a central power grid may be challenging or expensive. These communities can establish self-sufficient microgrids to meet their electricity needs, reducing dependency on external sources.	[34]
Industrial Facilities	Microgrids offer benefits to industrial sites by providing localized power generation and ensuring uninterrupted power supply. They help industries maintain operations during grid outages and can significantly enhance the reliability and security of critical processes.	[35]
Military and Defense	Microgrids play an important role in military applications, providing energy security and resilience in deployed or strategic locations. They support military bases, forward operating units, and critical infrastructure with independent power supply, reducing vulnerability to disruptions.	[3]
Smart Cities	Microgrids can be integrated into urban areas to support the concept of smart cities. By incorporating RESs, energy storage systems, and intelligent control algorithms, microgrids help optimize energy usage, reduce peak loads, and contribute to a more sustainable urban environment.	[36]
Emergency Response and Disaster Recovery	During natural disasters or emergencies, microgrids can quickly restore power to essential services like hospitals, emergency centers, and communication networks. Their localized operation enables faster recovery, facilitating relief efforts and improving community resilience.	[37]

The MG technology is an innovative approach to integrating RESs into the power grid and some of the MG technology applied are pointed out below in Table 4. It involves the deployment of localized, small-scale power grids that can operate independently or in conjunction with the main electrical grid [38]–[41]. In the field of renewable energy engineering, MGs are used to maximize the utilization of RESs by optimizing their generation, consumption, and storage.

Table 4 Microgrid Technologies

MG technology	Explanation	Ref
Renewable energy integration	MG enables the seamless integration of various RESs like PV systems, WT, and small-scale hydroelectric plants. These sources generate clean energy that can be used to power the MG and reduce dependence on traditional fossil fuel-based energy.	[42]
Energy management and control	MG employ advanced control systems to monitor and manage energy production, storage, and consumption. It uses real-time data analytics and forecasting techniques to optimize the use of RES. Includes balancing energy generation and demand, managing energy storage systems, and minimizing grid outages or blackouts.	[43]
Battery storage integration	MG often incorporate battery storage technology to store excess renewable energy generated during periods of low demand or high generation. These batteries can then be used during times of high demand or when RESs are not actively producing electricity. Battery storage helps balance the intermittent nature of renewable energy sources and ensures a consistent power supply.	[44]
Islanding capability	Microgrids can operate in "island mode," meaning they can function independently from the main grid during emergencies or planned disruptions. This capability ensures a reliable power supply to critical facilities like hospitals, military bases, or remote communities that may be located far away from the main grid.	[45]
Grid resiliency and reliability	By decentralizing power generation and incorporating RESs, MGs enhance grid resiliency and reliability. They reduce the risk of widespread blackouts by providing a localized power supply and minimizing transmission losses associated with long-distance power transmission.	[46]

3 Discussion

Table 5 Advantages of distributed generation in microgrid.

Advantages	Explination
Energy Reliability	DG reduces dependence on a centralized power grid by providing localized generation capacity, mitigating the risk of wide-scale outages. Microgrids with DG sources can operate independently or in conjunction with the main grid, ensuring a reliable power supply.
Power Quality Improvement	DG units can help maintain stable voltage and frequency, minimizing fluctuations and enhancing the overall quality of electricity supplied to end-users within the microgrid. This is particularly crucial for sensitive applications, such as hospitals or data centers.
Reduced Transmission Losses	By generating electricity closer to the point of consumption, DG reduces the need for long-distance transmission, thereby minimizing energy losses that typically occur during power transmission over extensive distances.
Enhanced Resilience	Microgrids with distributed generation can quickly restore power during grid disruptions, such as natural disasters or equipment failures. The ability to island and operate autonomously allows critical facilities to continue functioning when the main grid fails.

A localized network, such as a microgrid, or a variety of small-scale sources that are situated close to the end consumers are referred to as DG. The DG in MGs has gained considerable attention due to its potential to increase energy resilience, sustainability, and local control over power generation. As technology continues to evolve, ongoing advancements and innovations in this area will further enhance the performance and capabilities of microgrids. Moreover, traditional centralized power generation involves the production of electricity in sizable power plants and the long-distance transmission of that energy [46]. Microgrids are more compact forms of the larger electricity grid that can run alone or in conjunction with it [47]. They typically serve a localized area, like a community, campus, or industrial complex. Additionally, DG plays a vital role in microgrid systems providing localized power generation closer to demand centers. The DG generation for microgrids offers several advantages as listed above.

3.1 Future trends

In the context of distributed generation for microgrids, there are several future trends that are gaining momentum. Table 5 presents a few noteworthy ones which is an important to note that while these trends show promise, their widespread adoption and implementation may vary based on regional policies, technological advancements, and economic factors.

Table 5 Future trends of microgrid technology

Future trends	**Features**
Increased use of renewable energy sources	As the world shifts towards cleaner energy solutions, distributed generation in microgrids is expected to rely more on renewable energy sources like solar, wind, and hydropower. These sources are becoming increasingly cost-effective and can help microgrids achieve higher levels of sustainability.
Energy storage advancements	Effective energy storage is crucial for maximizing the benefits of distributed generation in microgrids. Advancements in battery technologies, such as improved energy density, longer lifespans, and reduced costs, are anticipated. This will allow microgrids to store excess energy during periods of high generation and utilize it during times of low output or high demand, enhancing overall grid stability and resilience.
Integration of smart grid technologies	Smart grid technologies enable enhanced monitoring, control, and optimization of distributed generation resources in microgrids. These technologies can help balance supply and demand, manage grid faults, and facilitate real-time communication between distributed energy resources (DERs). Integration of Internet of Things (IoT) devices, advanced sensors, and analytics will contribute to the efficient operation and management of microgrids.
Peer-to-peer energy trading	With the rise of blockchain technology, peer-to-peer energy trading is gaining attention. It allows energy producers and consumers within microgrids to exchange excess energy directly, bypassing traditional utility companies. This decentralized approach enables greater energy independence, cost savings, and increased resilience within microgrid communities.
Microgrid virtual power plants (VPPs)	Virtual power plants are emerging as an innovative concept in distributed generation. VPPs integrate multiple distributed energy resources, such as solar panels, wind turbines, and energy storage systems, into a single controllable entity. This aggregation of resources allows for optimal coordination and dispatch, enabling microgrids to participate in grid-balancing services and provide additional revenue streams.

Furthermore, there are also considerations to be taken into account with distributed generation for microgrids as presented in Table 6 below.

Table 6 Further direction studies of DG

DG study direction	**Discussion**
Cost and Scalability	The initial investment and ongoing maintenance costs associated with deploying DG units within microgrids can be higher compared to centralized power generation. Implementing and expanding DG systems require careful planning, financial analysis, and consideration of long-term benefits.
System Coordination and Control	Effectively managing DG units within a microgrid requires sophisticated control systems to balance supply and demand, ensure stability, and coordinate the operation of multiple distributed generation sources.

Renewable Energy Integration	While DG often includes renewable energy sources like solar panels or wind turbines, integrating intermittent renewable generation poses challenges for grid stability and coordination, as their output fluctuates with weather conditions.

4 Conclusion

To summarize, distributed generation within microgrids offers numerous advantages in terms of reliability, power quality, transmission losses, and resilience. However, careful planning, coordination, and consideration of factors like cost and renewable energy integration are crucial for the successful implementation and optimal operation of distributed generation in microgrid systems. The DG refers to the generation of electricity from multiple small-scale energy sources, typically located close to the point of consumption, within a microgrid. The concept of distributed generation has gained traction due to its potential benefits, including increased energy reliability, improved power quality, reduced transmission losses, and enhanced resilience during grid disruptions.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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