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Trends in Microgrid Technology: A Comprehensive Review

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Abstract

Microgrids are becoming an increasingly vital component of the energy grid due to their ability to improve grid resilience and alleviate grid disruptions by operating when the main grid is down and serving as a grid resource for more rapid system recovery. They are used to install distributed renewable energy resources, for example, wind and solar power, to minimize fossil fuel emissions as well as supply electricity to areas not covered by the main electrical grid. Microgrids are capable of addressing basic problems associated with widespread usage of dispersed generating. In this study, several elements of microgrids, including microgrid definition, architecture, microgrid drivers, stability, protection, and management strategies for microgrids, as well as their real-world applications, problems, and prospects, are examined in depth.

Keywords: Microgrids & their components, types of microgrids, Importance of microgrids, real-world applications, different control techniques, trends in microgrids.

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1. Introduction

The power system community is responsible for managing the electric power system, which is a complex and large network. The network continues to be defined by sharing a wide range of renewable energy sources. Increases in the use of renewable energy sources make it easier for power to be generated in different parts of the world [1]. The connectivity of renewable energy sources is becoming more of a trend in the distribution network as a result of technological improvements as well as environmental concerns. Microgrids are a kind of distributed power system that may operate inside existing distribution networks. Microgrids come in a variety of capacities. As a result of their ability to: (a) reduce the environmental impact and plant cost; (b) increase energy efficiency; (c) provide ride-through capability via energy storage; and (d) mitigate the effects of sudden grid outages, microgrids are gaining popularity.

Micro-Grid (MG) system is a small-scale grid that is positioned near customers. It connects tiny generators to low-voltage distribution networks and may be either grid-connected (connected to main grid) or isolated grid mode (not connected to any grid). Hydroelectric Power Plants with Small Capacity, Ocean Energy, and Biogas Plants Wind, diesel generation, photovoltaics, energy storage, and other energy resources are used in MG to electrify areas, primarily rural areas, where main grid electricity is unavailable due to a lack of technical expertise in remote places. Micro main grids must be designed in such a way that they are simple to install, commission operate, and maintain.

Most significant advantages of microgrids is to improve grid resilience [2–4]. Microgrids can continue to supply power in the event of a disruption to the main grid, such as a natural disaster or cyberattack because they operate as autonomous entities. This resilience is accomplished through the incorporation of sophisticated control systems and renewable energy sources such as solar and wind power, thereby decreasing the system's reliance on fossil fuels and increasing its overall dependability.

In addition, microgrids serve a vital role in the integration of renewable energy sources. Microgrids provide a platform for effectively capturing and managing renewable energy as the world transitions to a low-carbon future. Their decentralized nature enables the seamless integration of solar panels, wind turbines, and other renewable energy technologies, thereby reducing reliance on centralized fossil fuel-based power facilities.

The ability of microgrids to electrify remote areas is another significant advantage. Due to the difficulties associated with extending the main grid, access to electricity is restricted or nonexistent in many regions, particularly in developing nations. Microgrids provide a cost-effective and expedient solution by delivering electricity directly to these remote communities. This enhances their quality of life, fosters economic growth, and empowers both individuals and enterprises.

Besides introducing MG concept and its related topics, this paper presents a comprehensive review of MG components, & types of microgrids. Section 2 explains definitions of microgrids, their components, and various types of microgrids. Section 3 explains the importance of microgrids. Section 4 defines the real-world applications of microgrids. Section 5 describes microgrid challenges. Control methods for microgrids & changing trends of microgrids in the research area are given in sections 6 & 7 respectively. Section 8 defines the future prospects and growth of microgrids followed by the conclusion of this paper.

2. Microgrid

This section gives a comprehensive introduction to concept of MG, its components, structures, and microgrid types.

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2.1. Definition

An MG is a group of interconnected loads and DERs within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid. An MG can connect to and disconnect from the grid, enabling it to operate in grid-connected and islanded modes (as per IEEE standard 2030.7) [5-6].

A microgrid is a combination of controlled loads and decentralized energy supplies linked to the grid. A microgrid has flexibility to connect and disconnect from grid, enabling it to function in both grid-connected & island modes. To provide electricity to a small area, such as a campus, hospital, business district, or community, a microgrid can be set up. Microgrids are small electrical networks that provide power by combining several decentralized energy sources. These sources can include solar panels, wind turbines, CHP, and backup generators. In addition, numerous microgrids contain energy storage, which is frequently in the form of batteries as shown in Figure 1.

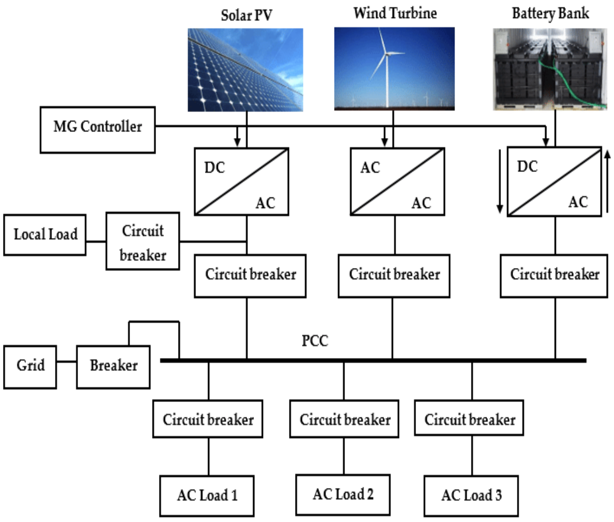

Fig. 1. Basic of Microgrid [9].

2.2. Microgrid Terminology/Components

The three main parts of any energy grid—generation, storage, and demand—are all integrated into one microgrid. These three components are all contained within a bounded and controlled network, as in Figure 2.

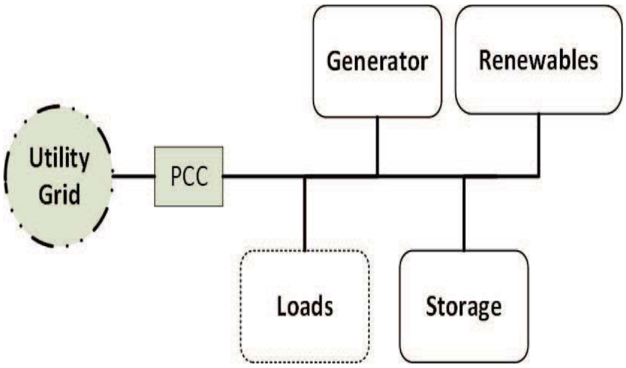

Fig. 2. Basic Components of Microgrid.

2.2.1. Generation Units

Generation units are micro sources (approximately below 10-100kw each); e.g., small wind generators, PV modules, fuel cells, Micro-turbines, etc.

2.2.2. Energy Storage

In a microgrid, energy storage may serve numerous functions, including power quality, voltage & frequency control, stabilizing renewable energy production, system backup power as well as cost optimization. Batteries, flywheels, and ultra-capacitors could all be used as storage devices [7-8].

2.2.3. Loads/Consumptions

Loads on a microgrid can be classified as either critical, general, sensitive, insensitive, as well as controlled or uncontrollable, depending on the availability of its power source. In microgrids, consumption refers to heating, and cooling systems, ranging from business centers to building heating systems.

2.2.4. Power Electronics Interfaces

Power electronic interfaces provide reactive power regulation at the source of generation. The majority of DG inverters are self-commutating and may supply an AC voltage with adjustable amplitude and phase. This characteristic enables DG systems to generate electricity at any PF. Inverters, dc-dc converters, and rectifiers are required in the microgrid interface.

2.2.5. Point of Common Coupling (PCC)

PCC is a point that connects main grid to microgrids of any electric system [10]. Isolated micro-grids, or those without a PCC, are typically found in remote locations where connecting with main grid is not possible owing to either cost or technological constraints.

2.3. Different Microgrids Structures [11]

On the basis of types of power supply Microgrids may be classified into 3 groups: AC, DC, and Hybrid Microgrids, as illustrated in Figures 3–5.

2.3.1. AC Microgrid (ACMG)

All of the AC microgrid's parts are linked together through a shared bus. Unlike other types MGs, ACMG can be seamlessly incorporated into standard AC power systems, allowing for more control and flexibility. Since DC components can't directly connect to the AC common bus, DC/AC converters are employed as intermediary, drastically reducing overall efficiency [12-14] as shown in figure 3.

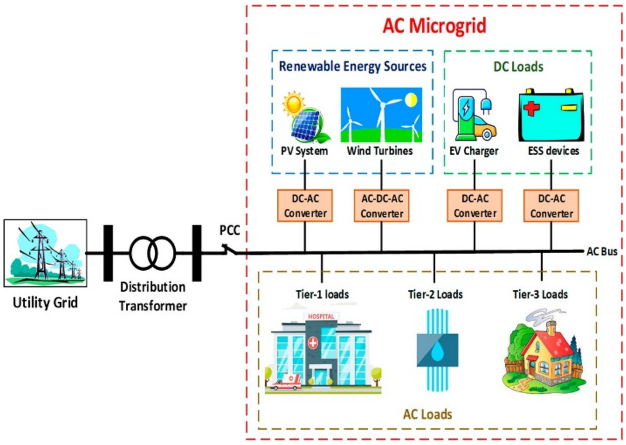

Fig. 3. Simple diagram of a typical ACMG.

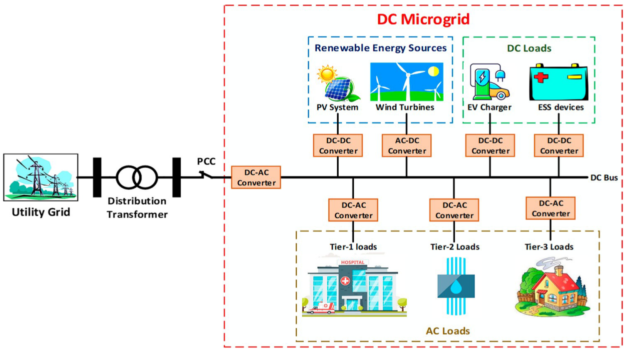

Fig. 4. Simple diagram of DCMG.

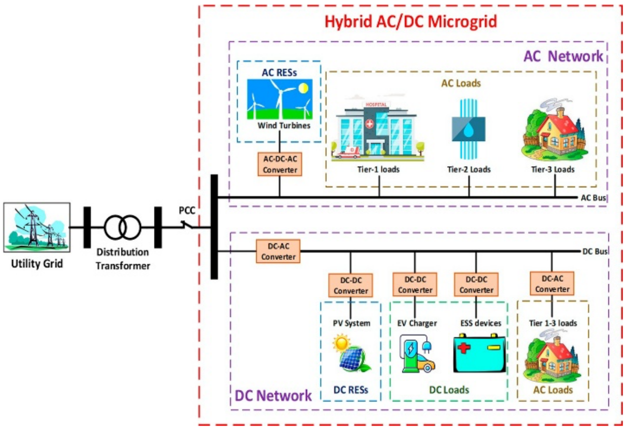

Fig. 5. Simple diagram of a typical HMG.

2.3.2. DC Microgrid (DCMG)

In DCMG, components are often connected to one another through a shared DC bus. A DC-to-AC power converter links them to the larger electrical network. DC and AC MGs are functionally equivalent from a conceptual standpoint. DCMGs are more efficient, cheaper to produce, and smaller in size than ACMGs due to their decreased power conversion losses and the fact that fewer power conversion stages are required. Bipolar, monopolar, and homopolar DCMGs are preferable to AC ones due to the lack of reactive power [12, 15-17]. Better alternatives for integrating DERs [12,15-17]. structures are examples of the most common types [12-14,18]. Figure 4 describes the general structure of a DC Microgrid.

2.3.3. Hybrid Microgrid (HMG)

They are the result of integrating ACMGs and DCMGs into a single distribution network. They are designed to have both AC and DC parts built right in. They use every benefit of ACMGs and DCMGs, including fewer interface devices, easier Distributed Resources integration, less time spent in conversion stages, reduced power losses, cheaper prices, and more dependability.

HMGs allow for direct connections between AC and DC components. Therefore, there is no need to synchronize creation and storage [19-21].

2.4. Microgrid Stations/Types

Microgrids are energy distribution networks that are localized to provide a single building or community with power. Microgrids are powered by different types of distributed energy (PV, wind turbines (WT), combined heat and power (CHP), and generators). Various types of microgrid stations as shown in Figure 6 are as follows:

2.4.1. Institutional/Campus Environmental Micro-Grids

Institutional micro-grids are aggregated with on-site production through many loads located geographically in which simple management takes place [22].

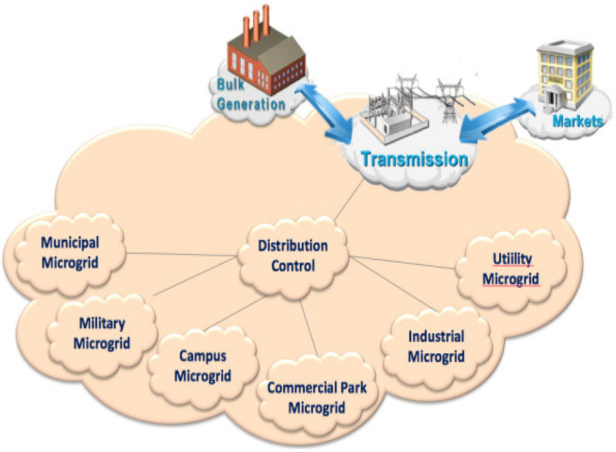

Fig. 6. Types of Microgrids.

2.4.2. Community Micro-Grids

These microgrids can only service a few thousand people while maintaining a restricted
power supply. A centralized or distributed energy storage system could be included in a microgrid. Microgrids can be of any type, including AC and DC MGs, like a hybrid microgrid [23]. They are connected via a bi-directional converter.

2.4.3. Remote off-grid Micro-Grids

Remote off-grid microgrids, are physically disconnected from the utility grid and always operate in island mode in absence of transmission and distribution (T&D) infrastructure nearby. Due to their geographical position and cost restrictions, these micro-grids rarely link to macro-grid & always function in an island mode. Typically, off-grid means Micro-grid i.e., not connected to utility grid is built, far away from a few transmissions and distribution infrastructure islands off-grid micro-grids. To overcome this problem via renewable energy sources and reduce cost of electrical energy production over life of such micro-grid projects [24-26]. In micro-grids, this will result in an unsuitable voltage along with frequency deviation. To ease such situations, an adjacent microgrid can be used to exchange electricity and achieve better voltage and frequency deviations [27].

2.4.4. Military-based Micro-Grids

These micro-grids are individually organized by equally physical also with cyber security for military services [28] to guarantee reliable power deprived of relying on scheduled Macro-grid.

2.4.5. Commercial and Industrial (C&I) Micro-Grid

Companies in the C&I sector are increasingly adopting low-carbon microgrids. Microgrids are localized energy networks that can function autonomously from larger power grids. The main motivations for installing these microgrids are security and power supply reliability. There are several modern procedures, primarily aimed at serving the needs of businesses and corporations, where a power outage can result in significant revenue losses and considerable start-up time [29].

3. Importance of Microgrid

Microgrids play a crucial role in energy challenges and have several significant benefits. Here are the key points highlighting their importance [30]:

3.1. Grid Resilience

Microgrids enhance grid resilience by providing localized power generation and distribution. During natural disasters, grid failures, or other emergencies, microgrids can operate independently and continue to supply electricity to critical facilities and communities. This improves overall grid reliability and reduces the impact of power outages.

3.2. Renewable Energy Integration

Microgrids help integrate renewable energy sources. Microgrids use solar panels, wind turbines, and other alternative energy sources to reduce fossil fuel use. It reduces climate change and greenhouse gas emissions.

3.3. Energy Efficiency

Microgrids enable efficient energy management and optimization. They can employ advanced technologies such as smart meters, (ESS) energy storage systems, and demand response mechanisms to balance energy supply and demand, reducing wastage and improving overall energy efficiency.

3.4. Electrification of Remote Areas

Microgrids provide electricity access to areas that are not covered by the main electrical grid, particularly remote or isolated communities. These communities often lack access to reliable power sources, and microgrids powered by renewable energy can be an effective solution. They enable economic development, improve living conditions, and provide education, healthcare, and communication opportunities.

3.5. Distributed Energy Generation (DEG)

Microgrids promote DEG, where power is generated closer to the point of consumption. This reduces transmission & distribution losses that occur in centralized grid systems, improving overall system efficiency. Distributed generation also enhances energy security by diversifying energy sources and reducing vulnerability to disruptions.

3.6. Peak Load Management

Microgrids can effectively manage peak loads by shifting demand and utilizing energy storage. During periods of high demand, they can draw on stored energy or prioritize supply to critical loads, reducing strain on the main grid and avoiding blackouts or brownouts.

3.7. Economic Benefits

Microgrids offer economic advantages by reducing the need for expensive transmission and distribution infrastructure upgrades. They can also provide opportunities for local job creation, particularly in the installation, maintenance, and operation of microgrid systems.

3.8. Fossil fuel emission

In a microgrid context, fossil fuel emissions can still be a concern depending on the energy sources used within the microgrid system. A microgrid is a localized electrical system that may function independently or in cooperation with the main grid. It primarily comprises of DERs including solar panels, wind turbines, batteries, and frequently incorporates backup generators.

4. Real-world Applications

Microgrids have gained significant consideration in recent years due to their numerous practical applications in various settings. These localized electricity distribution systems offer a range of benefits, including improved energy efficiency, enhanced resilience, and increased integration of renewable energy sources. Here are some real-world applications of microgrids and relevant case studies [31]:

4.1. Remote and Island Communities

Microgrids are particularly useful in remote or island communities that are geographically isolated and lack access to a centralized power grid. Implementing microgrids can help these communities achieve energy independence and reduce their reliance on fossil fuels [32].

4.2. Military Installations

Microgrids are vital for military locations since they offer a stable and safe supply of energy, guaranteeing operational continuation even during grid failures or attacks. These microgrids may combine renewable energy sources to boost energy security and minimize dependency on fossil fuels [33].

4.3. Industrial and Commercial Facilities

Microgrids offer significant benefits to industrial and commercial facilities, including improved power quality, reduced energy costs, and increased grid reliability. These facilities can integrate microgrids with renewable energy sources and energy storage systems to optimize their energy usage and reduce their environmental impact [34].

4.4. Urban Communities

Microgrids can be implemented in urban communities to enhance grid reliability, optimize energy usage, and support the integration of distributed energy resources. They enable localized electricity generation, consumption, and distribution, reducing transmission losses and improving overall efficiency [35].

4.5. Some Case Studies [36-37]

Microgrids are a hopeful solution to address the challenges of power generation & distribution.

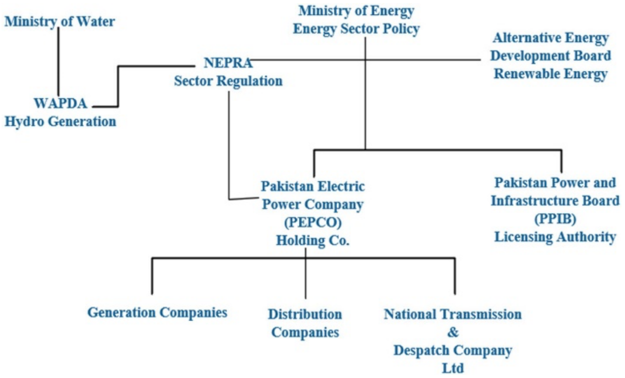

Fig. 7. Power Sector Organizational Structure of Pakistan.

4.5.1. Microgrids in Pakistan [36]

Pakistan's energy mix, with numerous conventional as well as RESs capable of meeting the country's energy demands as illustrated in Figure 8.

Despite possessing a varied energy mix, Pakistan nevertheless confronts various hurdles in achieving its energy demands. Most considerable difficulties is a lack of investment in energy industry, power theft, and bad management & maintenance. Another area for improvement encountered by Pakistan is the high cost of electricity.

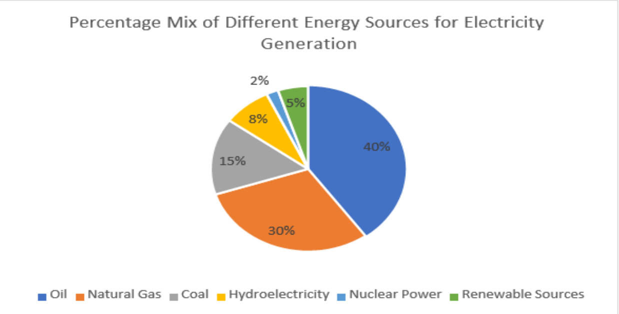

Fig. 8. Mix % of Different Energy Sources for Generation of electricity in Pakistan.

The organization of the electricity industry in Pakistan is represented in Figure 7. Pakistan has tremendous RE potential, notably solar and wind power. So far, a number of microgrid projects have been built in Pakistan.

Fossil fuel-based power production dominates Pakistan's energy business, creating air pollution, GHG emissions, and resource depletion. By integrating renewable energy and enhancing energy efficiency, microgrids provide a sustainable solution to environmental challenges. A microgrid's GHG (Green House Gas) emissions are strongly connected to its renewable energy [38]. Solar PV, wind, & biomass reduce emissions when utilized more. Demand-side management (DSM) methods, including demand response, energy efficiency, & load shifting, may minimize GHG emissions by optimizing energy consumption and decreasing fossil fuel power production. Solar and wind power generate fewer air pollutants, resulting in cleaner air and fewer health risks. Microgrids minimize urban air pollution [39]. Land use change, habitat loss, with other environmental impacts from large-scale power plants & transmission infrastructure may be mitigated by microgrids, protecting and boosting ecosystem services. Microgrids may minimize the necessity for large-scale infrastructure efforts that separate habitats and damage ecosystems [40].

Pakistan's microgrids can power rural villages. Pakistan's rural populations use diesel generators for energy instead of the national grid. Solar and wind-powered microgrids may replace these generators with greener, cheaper electricity. During power disruptions, microgrids may also aid the grid. Pakistan's electrical system suffers from technical challenges, theft, and sabotage. Microgrids can offer consistent electricity during outages, keeping hospitals and water treatment facilities running. Pakistan is also reducing microgrid costs. Solar panels & other components have dropped in price, manufacture microgrids affordable.

By supplying consistent and sustainable electricity to rural and off-grid populations, microgrids might help Pakistan's energy issue. Pakistan's government is likewise supporting microgrids as a solution to energy issues. However, technical skills and capability, regulatory issues, and finance must be solved for microgrids to attain their full potential in Pakistan.

4.5.2. Microgrid in India [37]

Remote Indians don't have power. The government has promoted renewable energy and locally accessible resources to establish electricity in rural regions. On one side, semi-urban and rural residents lack electricity. Urban residents, however, need consistent, high-quality electricity. India's wide geographical variety and different consumer preferences and needs make microgrids a better way to bridge the gap and achieve fair, sustainable, and quick economic development. India and emerging countries' economies are crucial. A microgrid's power must be equivalent to or cheaper than the primary grid's. Removing incentives like farm subsidies and kerosene for illumination, switching to smart meters to avoid theft, and extending microgrids.

Micro/mini hydro, biomass, and solar PV are India's major energy sources, although wind and natural gas are developing. Diesel-wind and diesel-biomass hybrid systems exist. Table 1 lists field project sources. Solar PV dominates these projects since it's abundant and available year-round.

Table 1. Indian microgrid projects—types of sources.

Projects/Developer	Mini hydro	Solar PV Wind	Biomass
Sidrapong hydel power station	No	Yes	No
Sagar Island MG	Yes	Yes	Yes
Dharnai solar city	No	Yes	No
Chhattisgarh Renewable Energy Development Agency (CREDA)	No	Yes	No
Decentralized Energy Systems of India (DESI) Power	No	Yes	No
Husk Power Systems (HPS) MG	No	Yes	No
Orissa Renewable Energy Development Agency (OREDA)	No	Yes	No
West Bengal Renewable Energy Development Agency (WBREDA)	No	No	No
	Yes	Yes	Yes
Uttar Pradesh New and Renewable Energy Development Agency (UPNEDA)	No	Yes	No
	No	No	No
Mera Gao Power (MGP)	No	Yes	No
Sikkim Renewable Energy Development Agency (SREDA)	No	Yes	Yes
Gram Oorja, Naturetech infra, and Minda Nexgen tech projects	No	Yes	No
Alamprabhu Pathar: Maharashtra Energy Development Agency (MEDA)	Yes	Yes	No
	No	No	No
Solar electricity company (SELCO) Foundation MGs	No	Yes	No
Amrita self-reliant villages	Yes	Yes	No
Gosaba Island project	No	Yes	No
Biomass energy for rural India projects	No	Yes	No

Most microgrids in India may be found in rural or otherwise out-of-the-way regions. In the event of a breakdown, this complicates the process of monitoring, repairing, and maintaining the system. The situation might be improved by studying three key areas: (1) PV module degradation factors, (2) power-electronic interfaces with clearly defined & progressively manifesting failure modes, and (3) remote monitoring and testing systems for interfaces and controllers.

Since the government prefers off-grid/microgrid solar PV power sources, PV module deterioration must be studied. Solar photovoltaic (PV) energy production is sensitive to both irradiance and temperature, while the performance ratio is affected by both location and technology. The nation is divided into five distinct climate zones, each with its own unique set of weather patterns. As a result, the modules' effectiveness varies depending on their placement to devise strategies for reducing its severity.

5. Challenges

Microgrid protection and control present several challenges due to the complex nature of these systems as shown in Table 2 [11].

5.1. Fault detection and isolation

The presence of distributed energy resources (DERs) and multiple interconnected components in microgrids complicates fault detection and isolation. Identifying faults accurately and isolating affected areas is crucial to ensure safety & reliability of system.

5.2. Islanding detection

Islanding refers to the condition when a microgrid operates in isolation from the main grid. It can pose safety risks for maintenance personnel working on the grid and hinder coordination with the main grid during restoration.

5.3. Power quality management

Maintaining stable voltage and frequency levels is essential for the reliable operation of microgrids. Fluctuations in power quality can impact the performance of sensitive equipment and disrupt operations.

5.4. Protection Coordination

Coordinating protection schemes in microgrids with multiple DERs and interconnected components is a challenge. Ensuring selective tripping during faults while minimizing unnecessary shutdowns requires careful coordination.

5.5. Cybersecurity

Microgrids, being digitally connected systems, are vulnerable to cybersecurity threats. Unauthorized access, data breaches, and cyber-attacks can compromise the operation and control of microgrids, leading to disruptions.

A detailed overview of challenges associated with microgrid protection & control is given in Table 2.

Table 2. Microgrid challenges and main technical & economic issues [11].

S. Nos.	Challenges	Descriptions
1.	Power Imbalance	Due to MSs' slow dynamic responsiveness & low inertia, switching from grid-tied to islanded mode causes power imbalances. DG failures and load changes may cause MG power imbalances [41].
2.	Stability issues	MGs and DERs pose stability & power quality issues in power systems [42]: (a) Lower network inertia causes frequency and voltage instabilities by decreasing angular stability. (b) Low-frequency power oscillations are caused by DER power-sharing ratio adjustments. c) Voltage stability decreases with lower energy distribution assistance.
3.	Low inertia	Microgrids differ from major power networks in that they have a low inertia characteristic, whereas synchronous generators ensure high inertia. If an appropriate control mechanism is not established during island mode operation, low inertia within the system might lead to substantial-frequency variations [43].
4.	Harmonics	Harmonics in power systems may affect system dependability and stability [41]. MGs use numerous PEL devices, power systems' principal harmonic sources. Harmonics may pose several issues, including ESS safety risks. Power systems reduce harmonics via active and passive power filtering.
5.	Topological changes	Intermittent RESs, MSs, loads, and ESSs may modify MG topology. MGs may be put in residences, farms, buildings, etc. MGs may be created to satisfy customer and system needs.
6.	ESS	DERs, such as RESs, may deliver clean, free, or low-cost energy, but they are difficult to manage [44]. These issues are solved by ESSs. ESSs reduce fluctuations, boost system power factor, manage frequency & voltage, also overcome RESs' intermittent nature.
7.	Environmental issues	Due to global warming, carbon emissions, high-quality power demand, and fossil fuel depletion, governments must increase the percentage of environmentally friendly DERs like RESs in their networks [45].
8.	Economic aspects	DER reactive and active powers and CSI/VSI interface bus current/voltage are key factors for MG governance [46]. Feeder and transformer losses may be managed in grid-tied mode by adjusting the MG output. An optimized energy strategy must be established for MGs as ESS utilization determines their lifespan [47-48].
9.	RESs Integration	RESs are intermittent, variable, and low-cost. These issues must be addressed while constructing control systems and employing ESSs to maximize RES integration with MGs.
10.	Protection issues	To safeguard the MG's components from main grid faults, protection system should promptly identify and isolate MG.
11.	Communication system	MGs are small, distant grids that need cost-effective, resilient, & reliable communication systems with enough coverage, security, & latency to operate properly.

6. Control Methods for Microgrid

Microgrids are self-contained and deliver dependable, high-quality electricity. The following are purposes of microgrid control:

1. Without altering current equipment, additional micro sources may be added to the system.
2. In any sort of critical fault or condition, a microgrid may connect or detach itself from grid.
3. Active and reactive power regulation may be separated.
4. Microgrid control may correct voltage sag or any other imbalanced scenarios.

Micro sources are separated into two categories: DC power supplies such as solar cells and battery storage also use fuel cells along with AC power supplies such as microturbines. DC voltage from both AC & DC voltage sources. Issues related to imbalance, Power transmission, Synchronization, and optimization generally demand control methods in a micro-grid [41, 49-51]. Primary control, Secondary control, and Tertiary control are three main control techniques as shown in Figure 9. Each of them is responsible for controlling the microgrid at a unique level as detailed in Table 3.

Table 3. Functions of various control levels Stability, Protection, Power.

Type of Control	Function
1.Primary Control	a. Protection devices, b. Sharing of Power, c. The stability problem of Voltage/Frequency in islanding mode, d. Primary current and voltage control
2. Secondary control	a. Control deviation of Voltage/Frequency, b. Control both power (Active and Reactive), c. Management during Black Start, d. Synchronization of Grid.
3. Tertiary control	a. Market participation, b. Management during Islanding and interconnection mode, c. Coordination of multiple MGs, d. Management of Fault, e. Optimization of various variables: cost, efficiency, etc.

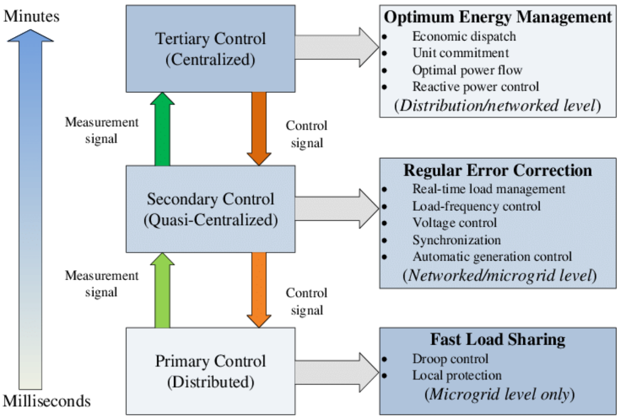

Fig. 9. Microgrid Control Methods [52].

6.1. Microgrids Control Methods

Various control methods for microgrids are as follows:

6.1.1. PQ Control

The Main Objective of PQ control is to ensure equality in generation of output active & reactive power to reference output power. It is necessary to use a DG or grid to sustain constant voltage as well as frequency.

6.1.2. Droop Control

It is equivalent to main frequency control in a power system. Because DG output active power & frequency have a linear connection, although reactive power & voltage amplitude do not, droop control may respond efficiently deprived of interacting with other DGs.

6.1.3. V/F Control

This is identical to ordinary power system secondary control. V/F control guarantees that DG voltage & frequency stay constant.

6.2. Microgrids Control Strategy

Control strategy research is significant and focuses on four primary areas: 1) power flow regulation in MG & decoupling control of active & reactive power; 2) adjusting voltage of each DG interface to maintain stable; 3) ensuring DG's fast response & sharing load under isolated island; and 4) smooth switch between islanding & networking mode. Switching between microgrids & off-grid mode, especially an unplanned off-grid smooth transition, should rely on millisecond-level islanding detection technology, excellent performance of the micro-power controller and central controller, a reasonable switching control strategy, the microgrid, optimal composite energy storage configuration, etc.

Two basic control strategies of microgrids are peer-to-peer strategy & Master Slave strategy as described.

6.2.1. Peer-to-Peer Strategy

Because of peer-to-peer control, each distributed system in microgrid has similar levels. It aids microgrid to be "plug and play." "Plug and play" refers to adding micro sources to microgrid without compromising control and protecting existing units. Droop control, which demands all micro sources to have virtually comparable exterior features to coordinate control of whole microgrid system, may be utilized to build a peer-to-peer technique. Droop control may be categorized into two types: 1st as f-P/Q-V droop control as well as 2nd as P-f/V-Q droop control. P/QV droop control generates an output frequency and voltage amplitude based on observed system frequency & output voltage of DG, whereas P-f/V-Q droop control generates an amplitude of output frequency as well as a voltage based on assessed output active as well as reactive power. Generates amplitude. P-f/V-Q control is more useful in an equivalent partner approach than f-P/Q-V control.

6.2.2. Master-Slave Strategy

Master-slave approach outlines a microgrid with a master controller and slave controllers that obey master controller's regulations and interact with one other. Microgrids do not need frequency control when linked to a bulk grid system that can maintain system frequency. When a microgrid is detached from the bulk grid, master controller should be responsible for maintaining system frequency, voltage, & power balance on its own via V/f management and regulation.

When primary controller employs V/f control, it is either single-master control or multi-master control. To restrict amount of clutter caused by several V/f control micro-sources, a single dedicated controller has just one high-power micro-source as a controller micro-source. Multi-master control can have a multi-master controller if there is a stable step control scheme in which the next-stage micro-control source always receives V/f control when output of previous-stage micro-control source reaches its upper limit & switches to PQ Control. When load demand is below generation, master DG of a master-slave system acts as an infinite bus, consuming power at a standstill and supplying more power whenever load congestion occurs generation. In this control method, Main controller must adapt to altering requirements of load, so only DGs with sufficient mass storage equipment or sufficient storage equipment can be used. Multi-master control mode also requires a high level of communication between master & slave.

6.3. Control of AC Micro Grids

Nowadays, control of an AC microgrid plays an essential function in the research field. Primary, secondary, and tertiary control level topologies have become popular owing to their efficient and optimum control in hierarchical control structure in [8], [42], [53-54].

6.3.1. Primary Control

The main purpose of this control is achieved by using a power regulator to precisely balance active and reactive power between DG blocks, a voltage regulator to maintain voltage magnitude and frequency at VSC terminals, and a current regulator to achieve required current. As a result of this, it offers both centralized and distributed control approaches for power sharing within the converter as well as internal regulation of output voltage and current. Additionally, it regulates the output voltage and current. Primary control explains the control level with fastest response time, and it consists of islanding detection, power-sharing, and output control [55]. For primary controls, it is necessary to identify linear and non-linear forms of current regulators. Linear controllers include state feedback, synchronous rotating reference frames for PI controllers, and fixed Proportional Resonant (PR) reference-based predictive & aperiodic controllers [56]. Hysteresis, sliding mode, Delta Modulation (DM), Neural Networks (NNs), and Fuzzy Logic Controllers (FLC) are some examples of nonlinear controllers [56]. Voltage & reactive power of a DC link (considered active power) are regulated by active (in-phase) along with reactive (quadratic) components of network current, respectively. Various steps of Primary control techniques are given in next few subsections.

6.3.1.1. Centralized Primary Control

Several DC-AC converters operate in P Q mode in grid-connected mode because grid determines voltage besides frequency references. They may, however, adopt a master-slave controller-based method in islanded mode [57-58]. The single master converter works as Voltage Source Converter, while additional converters (slaves) function as CSC (Current Source Converters) in PQ mode [58]. Droop control is utilized by master converter to establish voltage along with frequency references for a microgrid. Set-point values of P Q mode, derived from a central controller, are utilized to inject specified active & reactive power into slave converters. In an islanded mode of operation, numerous converters can operate as VSC (Master) in Multi-Master Operation (MMO), while other converters operate in PQ control mode [58]. In [23] and [26] a technique that distributes current in an equal manner called Central Limit Control (CLC) is developed. Multiple modules with same setup and tracking average load current are used in CLC operation. However, in real-world CLC scenarios, converter modules may be configured differently, making equal current distribution impossible.

6.3.2. Conventional Droop Methods

In islanded microgrids, frequency and voltage are managed using classic droop tactics such as Pf and QV droop methods [59-60]. If V_mgo is known as inverter-based DER output voltage and E is known as inverter-based AC common bus voltage, then equations for active power (P) & reactive power (Q) for lead wire are assumed to be proportional to phase angle (δ) as shown in equations 1 & 2 respectively.

$$P = \frac{V_{mg}}{E} X\delta \tag{1}$$

$$Q = \frac{V_{mg}}{E} - \frac{V_{2mg}}{X} \tag{2}$$

Typical droop equations are not relevant to distribution networks if they do not have extremely resistive characteristics. Power Factor (Pf) droop features of microgrids allow for a frequency drop of voltage at output end along with an enhanced output real power of inverter, although QV droop lowers voltage magnitude at output end along with a rise in reactive power (Q) production. In old power plants, droop control mimics inertial capability of SM (Synchronous Machines) to regulate generation & demand incongruities by stabilizing frequency [58]. However, during grid disturbances and power outages, frequency and voltage quickly diverge from their normal levels, producing instability.

The disadvantages of traditional droop control strategies are as follows [60-61]:

- Only inductive transmission lines are valid for droop equations. They are ineffective in low-voltage, high-resistive distribution networks.
- There is a fundamental trade-off between the controller's time constant as well as frequency regulation. Reactive power control results in poor voltage regulation for critical loads. Because harmonic current sharing is not incorporated into conventional droop approach, it is inapplicable for nonlinear loads as well as single-phase loads.
- It is susceptible to frequency changes caused by the load. Unequal distribution output impedance between DER along with load causes poor power-sharing across DER components.

6.3.3. Improved Droop Methods

In this sections, summary of enhanced droop control approaches is presented.

6.3.3.1. Voltage-Real Power Droop/Frequency-Reactive Power Boost (VPD/FQB) (Droop Control)

Low voltage resistive distribution lines can benefit from VPD/FQB droop control presented in [62]. As active power output rises, inverter's voltage magnitude is reduced (Drooped), but frequency is boosted (Boost) as reactive power output rises. VPD method is system-dependent and useless with nonlinear loads but in low-voltage AC resistive lines considerably improves power-sharing.

6.3.3.2. Reactive Power–Voltage Differential, QV Droop Control

In [63] propose a reactive power distribution method using QV droop control and independent of output line impedance. The voltage recovery circuit holds V = 0 to maintain a constant output voltage. This method is highly dependent on initial conditions and is resistant to destabilization.

6.3.3.3. Angle Droop Control

The frequency variation is significantly lower for the angle droop control than for the frequency droop control, as shown in [64-65]. The phase angle of a VSC's output voltage may be measured using communication mechanisms like Low bandwidth GPS-based. Conversely, an inductive impedance is assumed for the VSC and the AC bus of a microgrid. Load-sharing accuracy for a weak system [64] is enhanced by high-angle droop gain in conjunction with supplemental control loop.

6.3.3.4. Virtual Frame Transformation

Using linear orthogonal transformation matrix [43-45] P & Q flow equations are referred to as novel reference frames in which they are not dependent on-line impedance.

6.3.3.5. Virtual Impedance Method

In [41], [50-51], [60] which contain virtual impedance in voltage control loop's feedback channel, using virtual impedance technique. When nonlinear loads are provided, THD of VSC output voltage may be taken into consideration. HPF used for this problem solution.

6.3.3.6. Adaptive Droop Control (ADC)

To improve voltage regulation, this avoids the use of an impedance between VSC and voltage control point when voltage drops change. As a result, QV droop management incorporates voltage decreases across connection impedance between VSC as well as common AC bus. It performs similarly to a traditional one under medium and low loading circumstances. In [66] proposes a transient reaction for paralleled inverter droop management in a microgrid. This droop control reduces transient circulation current and enhances transient response. In [67] proposes a dynamic and transient droop increase adaptive droop control. The improved structure incorporates a 2-DOF tuneable controller, with static droop gain preferred to control voltage magnitude, frequency as well as transient gains [67]. In [68] present an ADC with line voltage & line impedance to calculate line connected and isolated VSI. PID-based compensators are used for the equations that involve active power (P) and angular droop. On the other hand, PI-based compensators are used for computations that involve reactive power (Q) and inverter voltage droop. Transient amplification is present, as can be observed by modeling a weak signal of the system, which causes the transient response of the system to rise.

6.3.3.7. Virtual inertia-based droop control

In [69]] propose, an improved droop control mechanism to introduce virtual inertia into system. The goal of increasing inertia of the system is to prevent circuit breakers from tripping due to relay misoperation.

6.3.3.8. Nonlinear Load Sharing and Unbalanced Power Flow Control

High-frequency signal injection [70] can mitigate negative effects of imbalanced power flow in lines. The proposed method is not depending on changing values of system parameters or mismatching of line impedance. Because the power distribution network is injected by a high-frequency control signal. Values that are divided, such as active power, reactive power & distortion power affect frequency of control signal. Harmonic current sharing across paralleled converters is achievable by utilizing the approach outlined in [71]. The harmonic output voltage of converter is set 90 degrees ahead of output current. By multiplying the inverter's reference voltage by the harmonic voltage at each harmonic frequency, which is calculated from harmonic current & inverter's output impedance, effect of harmonic voltage on inverter's output voltage is lessened. On other hand, harmonic attenuation controllers need harmonic voltage calculation for each harmonic frequency. To compensate for impact of line impedance, [72] proposes a control technique based on negative virtual harmonic impedance. This allows harmonic power distribution while maintaining voltage quality of load bus. By reducing effective impedance of harmonic component lines along with adding a voltage drop to an inverter reference voltage, this approach provides harmonic isolation.

6.3.4. Secondary Control

The microgrid's Energy Management System is responsible for secondary control (EMS). After primary level droop control actions have caused a decrease in frequency and voltage in the microgrid, it is responsible for recovering these values and enhancing power quality. It's also responsible for a resynchronizing microgrid with utility grid and ensuring that DER units within the microgrid are operating optimally and in concert [61]. In islanded mode, frequency, as well as voltage error deviations, are managed by secondary control to generate control signals for error rectification, which are forwarded to a primary controller [61]. The operation of secondary control is implemented as centralized, decentralized, or distributed. The following section provides an outline of distributed & centralized approach in ACMG.

6.3.4.1. Distributed Approach

Recently need for a distributed control strategy is being examined [60-61], [73] as many DG units used in microgrids grow. It's used at secondary and tertiary control levels, as well as Micro Grid Central Controller (MGCC), at a medium voltage level. Microgrid components can interact more effectively thanks to distributed control, which boosts the grid's dependability, security, optimality, autonomy, and intelligence. Unlike centralized control, local controllers may communicate and make judgments. Each DG unit's local controller participates in a distributed EMS by exchanging information with other controllers and making control decisions based on both the local and global environment. Many organizations use some form of the methods described below to implement dispersed control.

6.3.4.1.1. Multi-agent-based Techniques

A real or virtual organism [74] that can be placed in an environment, & also can respond autonomously to variations in this environment is most important component of a Multi-Agent System (MAS)-based system. The intelligence of a multi-agent system is defined by its response to environment, pro-activity, and social ability [55]. In [74] proposes multi-agent hybrid EMS for microgrids along with central and distributed control based on network contract protocol, multi-factor evaluation, and market competition coordination mechanism. In [55], a multi-agent approach for energy applications is explored in detail. In a recent paper [74], researchers created a multi-agent co-management framework to coordinate many autonomous microgrids.

6.3.4.1.2. Model Predictive Control (MPC) Methodologies

MPC is a future approach that uses demand and generation forecasts to optimize a dependent variable model. It handles power system limits and solves multivariable optimization problems using predictions and feedback mechanisms [64-65], [75]. Using reactive power control [76], we investigate a voltage prediction method to prevent voltage instability in island microgrids. [77] propose a two-tier MPC approach to microgrids based on PV diesel generator batteries to improve uncertainty immunity. Authors of [77] offer a novel strategy for adjusting diesel generator switching time control & addressing Boundary Value Problem (BVP) by utilizing reference values from first layer.

6.3.4.1.3. Consensus-based Control Techniques

A load restoration system that is built with Multiagent technique is suggested by this article [78], in which agents make choices relying on local information from their local neighbors as well as global information relying on ACT (Average Consensus Theorem). In [79] proposes a topology for two-level control, in which upper level is used as consensus-based microgrid generation/demand optimization, and lower level is a principal local controller that ensures optimal system operation. In [80], voltage unbalance mitigation & negative sequence current sharing are improving via a dynamic consensus-based control strategy.

6.3.4.2. Centralized Approach

The Micro-Grid Central Controller (MGCC) handles the distribution of electricity to the numerous Local Controllers in a centralized method. Micro-source load controller is integrated into LC. Effective and dependable MG operation requires two-way interaction between the MGCC and the LC. Nonetheless, power outages may be caused by a single failure point. In decentralized control, LC regulates DER units using local measurements rather than a central controller. Online optimization for calculating input parameter values such as operating setpoints, limitations, network parameters as well as information of forecasting is a fundamental benefit of centralized control technique [50],[61].

6.3.4.3. Tertiary Control

Tertiary control uses to maximize the operation of a microgrid by managing flow of power between microgrid & utility grid as well as communicating requirements from host grid for example voltage & frequency regulation [41]. Distribution Management System (DMS) provides power references to tertiary control, which processes difference between actual and reference values. This control's output voltage and frequency references can be seen in [81]. It's the most gradual kind of authority in a hierarchy. The utility and its references are sent into the compensators, which then process the difference between P and Q. Secondary control voltage and frequency information is provided [61].

6.3.5. Methods of Intelligent Control for Primary and Secondary Levels

Control using intelligent approaches is a key study field in implementations that use power electronics-based converters. There are fuzzifier, rule evaluators as well as Defuzzifier common aspects of an intelligent control using fuzzy logic, coupled with rule basis & database. Paper [82], suggested FLC of a three-phase space vector PWM rectifier. For identifying switching patterns as well as calculating switching instants by utilizing magnitude with an angle of reference voltage vector, which is given by FLC. A 16-bit microcontroller (68HC16) is utilized to implement classic Space Vector PWM with FLC [82]. In [83] develops a fundamental frequency control approach for variable-speed wind generators based on FLC. At all wind speed ranges, FL supervisor assigns pitch angle as well as power reference to converters. A significant advantage of this technology, i.e., to maintain primary power reserve independent of wind speed by altering pitch angle as well as generator torque through FLC [83]. However, in this scenario, sudden load shifts, and fault occurrences were not taken into consideration. For optimum control of frequency tuning in AC microgrid, integration of FLC with Particle Swarm Optimization (PSO) is employed [84]. Artificial Neural Networks (ANN) are computer models of Biological Neural Networks (BNN), and they are a form of intelligent control. In microgrids, neural networks are utilized for estimate of parameters, forecasting of load, island identification, as well as control operation. In [85] presents a voltage and frequency management droop controller based on ANFIS (Adaptive Neuro-Fuzzy Inference System). To train ANFIS, an I/O data set is necessary which is collected using droop control approach. Line parameters and model settings are unaffected by this technique. However, it adds to system's computational burden. In [86] employs a neural network to manage peak wind power extraction, and assess wind speed, while correcting potential of turbine power coefficient characteristics drifting.

6.3.6. Highlights of AC Microgrid Control Techniques

There has been much interest in a study on control elements of AC microgrids since 2003 [87]. Numerous control techniques are employed in AC microgrids at main as well as secondary control levels. Here are some of most significant features of AC microgrid control.

- Depending on system characteristics and current operating circumstances, suitable control should be utilized.
- VPD/FQB droop enables improved control for excessively resistive lines without harming voltage and frequency regulation.
- In [76], [88] displays improved voltage control with minimal influence from system parameter change.
- A hierarchical control strategy enhances frequency and voltage regulation as well as load sharing [61].
- In unbalanced microgrid systems with non-linear loads, effective control strategies such as application of high-frequency signals, distribution of harmonic currents, and setting of appropriate and adaptive output impedances can achieve real-world load sharing [69].
- Droop control and other communication-less control strategies are unaffected by distance between DGs with their associated loads. However, since there is no contact between DGs, they are less trustworthy.
- Decentralized control approaches are getting popularity because they have a lesser likelihood of single-point control failure than centralized control strategies, intelligent control as well as cooperative and multi-agent-based approaches.

6.4. An Overview of DC Microgrid Control Techniques

DC microgrids offer following probable benefits over AC microgrids [89]:

- Reactive power and frequency regulation do not need any control.
- There are no grid synchronization problems.
- Because there is no transformer, there is no inrush current.
- Inverter conversion losses are lowered.
- It has the potential to fault-ride on its own.

However, there are several downsides to adopting a DC microgrid:

- There is a required building of private DC distribution lines.
- Because DC systems lack a zero-crossing point of current, protection is more complicated than in AC systems.

Active power flow only influences voltage stability, but reactive power may regulate AC system voltage without influencing active power. Centralized control [90-91], master-slave [92-93] average load sharing [94-96] and circular chain control [97-98] are all power-sharing along with control systems for multiple inverter operations utilizing parallel DC-DC converters. For simultaneous operation of inverters, droop control techniques are also applied [61]. In literature, two control strategies for DC microgrids have been informed: a communication-based centralized control approach in which central controller delivers reference voltage as well as power setpoint for constant voltage as well as power output operation [61] and a communication-based distributed control approach in which a distributed controller delivers reference voltage or power setpoint for distributed control [99]. However, in terms of distributed control, local controller regulates output power of DG devices based on local measurements with minimal communication requirements and no central controller required.

6.5. Introduction of Control Strategies with Hybrid AC-DC Microgrid

Hybrid microgrids [100-102]] consist of AC and DC subnetworks connected by bidirectional junction converters (ICs). By having distinct AC and DC networks, an AC-DC hybrid microgrid may link diverse AC and DC RES while also reducing reverse conversion [99, 102]]. Based on the analysis of hot literature on hybrid microgrid control research, problems in hybrid microgrids may be classified as follows [103-105].

- Voltage, as well as frequency control maintenance in a hybrid microgrid, is far more complex due to lack of global variables which can be leveraged for power-sharing.
- Even with normal P-f & Q-V droop control, power-sharing among Ac / Dc microgrids isn't achievable in autonomous mode.
- A specified droop mechanism should be implemented by Power Management System (PMS) to distribute power demand across current AC and DC sources.
- Harmonic power-sharing should be addressed as nonlinear loads are incorporated in microgrid loads.
- It is vital to make a compromise between control of voltage and sharing of reactive power.
- The aforementioned droop control, for optimum load sharing between AC and DC sources, must be insensitive to impedance of line connecting inverter to AC/DC bus.
- To maintain microgrid working smoothly and reliably, a strong energy management system may be implemented.

Compared to AC or DC microgrids, hybrid microgrids have more complex energy management, and control in addition to operation. Hybrid ACDC microgrid topologies have been proposed by [106-107], [102], [104]. In [105] and [107] both provide autonomous control of hybrid microgrids. In [108], the authors detail a strategy for real-time power management in an ACDC hybrid microgrid that makes use of hybrid energy storage to lessen the impact of transient loads. Power control and management techniques for different hybrid microgrid topologies are summarized in [101], which covers both steady-state and transient operations. This includes both alternating current (AC) & direct current (DC) networks and AC & DC-linked systems. A hybrid microgrid supporting voltage in DC connection of an inverter is used as a DC bus [103] and various operating scenarios such as DC bus failure are investigated. A hybrid microgrid interfaced with a parallel AC/DC bus converter is shown to be controlled hierarchically [81].

Summarizing, the following are some of hybrid microgrid's control highlights:

- For effective and reliable power flow regulation, a rather complex control strategy is necessary.
- An extra interlinking converter among AC in addition to DC sub-grids is vital for power balancing in each operation either grid-connected or islanded mode.
- Lack of comprehensive variables in AC & DC sub-grids adds another layer of complexity to hybrid micro-grid management.

In [106-107] indicates hybrid AC-DC droop, according to unitized voltage & frequency regulation on each side (AC-DC sub-grids).

7. Changing trends in research of microgrid

The research on microgrids has been evolving rapidly in recent years, driven by the increasing interest in renewable energy, decentralized power generation, and energy resilience. Here are some changing trends in the research of microgrids:

7.1. Multi-microgrid Operation with its Control

In proposed, idea of a multi-microgrid, which distribution system is divided into numerous microgrid-like zones. This is done to put smart grid ideas like self-healing, resilience to shocks, deliberate islanding, & other elements like microgrid dynamics into action. The operation and management of many microgrids is a topic that deserves additional investigation. In [109-110] examine multi-microgrid voltage control as well as MAS-based energy management.

7.2. Energy Storage Management

Energy storage integration has expanded in tandem with increasing DER penetration in today's electrical grid. The use of DES units helps reduce the inherent unpredictability of the power production from stochastic generating units, such as solar and wind energy conversion systems. Microgrids will include a reasonably high number of innovative gadgets that are capable of passive energy storage. The adoption of electric automobiles on microgrids is also making steady progress and increasing pace. They can help grid by acting as both controlled loads along with generators [111], ensuring supply continuity. In this area, more research on control aspects & power management is necessary.

7.3. Active Load Management

Current loads influence microgrid's overall dependability and stability. In an active load management system, quantity of energy utilized by customers is decided by power system's operating conditions. Loads may be lowered during a grid outage to lessen the chance of a power loss. Active load management [112] helps decrease power and frequency variations. This component may be investigated further to maximize generation and grid capacity utilization, boost reliability, and enable large-scale RES integration.

7.4. Hybrid Distributed-Centralized EMS

In a microgrid, EMS oversees functioning of micro sources and their controllers safely and efficiently. As described in earlier sections, distributed control at a secondary level of hierarchy promotes dependability by avoiding single-point failure. As number of RES rises, centralized EMS may give an ideal solution with reduced communication intricacy. A coordinated operation of distributed along with centralized controllers, on other hand, may reach an optimum and dependable energy management aim. Because at secondary control level, agent interaction and supervisory intervention may be employed to achieve dependability and optimality. In [113] creates a hybrid distributed control system with a supervisory control system for realistic DC microgrids.

7.5. Application/Uses of Soft-Switches (SS)

SS that replaces normally open contacts uses power devices such as continuous VSCs. They [114] provide a variety of active & reactive power control including power recovery, voltage monitoring, which also included fault isolation. This switch might be installed close to non-critical loads to help with load balancing and to improve the quality of the energy supplied by the mains. When placed in a suitable and ideally located network, soft switches can increase resilience of microgrids.

7.6. Control, Protection along with Stability

DC-microgrid protection is a difficult problem to solve due to lack of zero-crossing current. Further study on DC-microgrid protection is necessary to enhance protection systems. Controlling a microgrid using clusters, employing electric cars as active load & incorporating smart metering along with two-way communication technologies may all be studied further [99], Microgrid stability analysis offers a safer approach to real-time design implementation. Voltage, as well as frequency stability under small & significant disruptions, is a basic condition for a microgrid's dependable & efficient operation. Frequency stability is not an issue with DC microgrids, but it is in AC microgrids. Microgrid's frequency is maintained in grid-tied mode by a utility. However, unless voltage magnitude & frequency of VSC are regulated and also maintained, microgrid system would face huge oscillations owing to accidental islanding. Studies of frequency stability in an islanded microgrid under large shocks are still a work in progress. Frequent deployments of constant power loads with line regulating converters reduce voltage stability margin of a DC microgrid as well [115]. To enhance voltage stability in DC microgrids, new control techniques must be studied.

7.7. Metaheuristic Optimization-based Control

Metaheuristic techniques, as opposed to typical optimization tactics, are effective in tackling complex optimization issues because they replicate nature's best features. They are non-deterministic as well as produce close-to-optimal results. Many types of evolutionary algorithms, such as PSO (Particle Swarm Optimization), ACO (Ant Colony Optimization), and bacterial foraging, are based on swarm intelligence [116]. Other examples of swarm intelligence-based algorithms include Clonal Search, Harmony Search, and differential evolution. The most often used metaheuristic approaches are GA as well as PSO. These algorithms were used to increase power quality, adjust controller parameters, as well as lower costs for optimal microgrid operation. Microgrid systems now have more intricate control because of advancements in power electronics. To appropriately optimize as well as control the functioning of systems, more research has to be conducted on a wide variety of metaheuristic algorithms and their hybridization. As a consequence, this is a growing topic of study interest in issue.

7.8. Game-theoretic Control

Game theory is a mathematical approach that encompasses a collection of analytical and conceptual tools when studying complicated interactions between autonomous yet strategic participants [84]. Noncooperative game theory, for example, has recently made its way into microgrid research as a tool for addressing intricate optimization issues and predicting their outcomes, particularly when players make decisions noncooperatively, that is, without communication [117]. A non-cooperative game theory solution concept is Nash equilibrium. Some work on applying these ideas to microgrid communication and controls has been published [117], [106-107], [104] & [118] uses classic game theory methods to offer centralized LFC combined ELD for just a microgrid. An approach for Population games is utilized in [119] to dispatch economic active & reactive power as well as demand response. The replicator dynamics model is utilized to tackle the optimization issue. Replicator dynamics include a small number of agents who pick from a restricted choice of strategies. Game theory's application to microgrid control is still in its early stages, thus further research is needed.

7.9. Information & Communication Technology (ICT) in Microgrid

Because of fast growth of Information and Communication Technologies (ICTs), practical and cost-effective monitoring and control systems allow for significant intra & inter-utility data exchange, dispersion, & open access to real-time data [120]. As a consequence, they're being employed to maintain microgrids working effectively and dependably. Advanced Metering Infrastructure (AMI), is a two-way communication network, enabling data to be acquired and transferred between smart meters and utilities [121]. Use of AMI could be a potential alternative for smart as well as efficient microgrid operation. Some of current microgrid communication technologies include Zigbee, Power Line Communication (PLC), Cellular Network Communication (CNC), also Digital Subscriber Lines (DSL). Trustworthy communication infrastructure is essential for microgrids and other microgrid solutions to operate. As a consequence, they're a vital aspect of a microgrid. More research is needed on innovative communication technologies to improve overall system reliability & efficiency in fields of microgrid management, demand management along power quality improvement.

8. Future prospects of Microgrids

The future prospects of microgrids are promising, with emerging trends and technologies set to further enhance their efficiency and effectiveness [36]. Potential applications, future trends of microgrids are elaborated in next section.

8.1. Microgrid's potential application areas

The potential microgrid areas for research and development are shown in Figure 10.

a. This includes the transportation sector in which there is a continuous requirement of reliable as well as efficient stations for an electric vehicle.

b. microgrids can also be used to provide secure & reliable power as well as sustainable & resilience energy systems to the military.

c. Community based microgrids can promote social equity and help communities to manage their needs of energy actively.

d. Resilience & sustainable microgrids can help to attain better energy security and minimize the risk of power outage & disruptions.

Fig. 10. Microgrids' potential areas for research and growth.

8.2. Emerging trends & technology to enhance the performance of microgrid

Various technologies for the enhancement of microgrid performance are as follows:

8.2.1. Blockchain technology

Blockchain may reduce fraud and improve energy market efficiency by recording energy transactions more securely and transparently [122]. In microgrids, blockchain technology might provide incentives for renewable energy use. Despite its potential advantages for microgrids, blockchain technology adoption is difficult. In microgrids with limited computational capabilities, blockchain technology's scalability and energy efficiency might be difficult.

8.2.2. Use of Artificial intelligence and machine learning in Microgrid

AI and ML microgrid optimization is another major study area. Microgrid systems may be optimized using AI and ML. New AI and ML tools and protocols are needed for microgrid data collection and analysis [123]. This development may analyze massive amounts of data in real-time using improved sensors, data analytics tools, and novel algorithms. Open and responsible AI and ML use in microgrid development [124]. New standards and best practices may be needed for microgrid development using AI and ML.

8.2.3. Role of microgrids in achieving sustainable and reliable energy system

Global sustainability concerns are complex and linked problems that affect the world, its ecosystems, and its people. One of the biggest global sustainability challenges is greenhouse gas-induced climate change. It causes severe weather, sea-level rise, ocean acidification, and ecological and agricultural changes [125]. Climate change may worsen socioeconomic inequality and disproportionately harm disadvantaged people. Global sustainability is threatened by overconsumption of fossil fuels, minerals, water, and arable land. Resource shortages, environmental degradation, and socio-economic problems may result from unsustainable resource exploitation and use. Long-term sustainability requires using renewable resources and improving resource efficiency [126]. Environmental degradation includes deforestation, biodiversity loss, air, water, soil, and fish supply depletion. These problems may reduce water filtration, carbon sequestration, and pollination [127].

9. Conclusion

Microgrids are a promising new technology that might transform power generation and distribution. This article discusses its advantages over conventional electricity networks, including dependability, resilience, and efficiency. Microgrids can also help to reduce our reliance on fossil fuels and improve environmental quality.

The development of microgrids is still in its early stages, but the technology is rapidly evolving. As the cost of renewable energy sources continues to decline, microgrids are becoming more and more cost-competitive. Thus, combined with the increasing demand for reliable and resilient power supplies, is expected to drive the growth of the microgrid market in the coming years. This article provides a deep insight into microgrid technology including its definition, structure, types, control method & strategies, challenges & real-world applications. In addition, the potential impact of microgrids on the energy sector and their role in achieving sustainable & resilient energy systems is discussed.

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