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Challenges in Integration of RES and Control Techniques in Microgrid: A Review

SINDHU M,
Research Scholar, Department of Electrical Engineering,
University of Visvesvaraya College of Engineering,
Bangalore.

Dr. Madhusudhana J,
Associate Professor, Department of Electrical Engineering,
University of Visvesvaraya College of Engineering,
Bangalore.

Abstract:- Microgrids have gained extensive attention over the prior 20 years and are alleged to be a substantial compound of impending power systems. The main objective is to essence the carbon footmark and to enhance the utilisation of Renewable Energy Sources (RES). Integrating distributed energy resources to create a microgrid will be tremendously vital. The development of modern and future electricity networks, like the smart grid, is influenced by MGs because they can provide a variety of benefits to the increasingly complex and growing power system, like better power quality, increased efficiency, enhanced system integration of energy sources that are renewable and clean, and improved network stability and reliability. Microgrid implementation has difficulties controlling, operating, and protecting since integrating RES into the system is more difficult. This paper comprehensively presents the different novelties in integrating RES, control, and optimization.

Keywords:- *Control and Optimization Techniques., Integration Challenges, Microgrid Renewable Energy Sources.*

I. INTRODUCTION

Massive amounts of electricity, mostly from fossil fuels, produced by large power plants are distributed to distant load centers via the conventional grid. The grid is currently dealing with security concerns, a limited supply of fossil fuels, growing challenges in extracting fuels, and volatile fuel prices, which have raised global concerns and jeopardized the global economy [1]. Using alternative energy sources to decentralize the production of electricity can help with some of these issues. A rise in renewable energy sources makes it possible to share the production of electricity globally [2]. The trend towards the distribution network in the interconnection of renewable energy sources results from both industrial advancements and environmental concerns [3]. A rise in renewable energy sources makes it possible to share the production of electricity globally. The trend towards the distribution network in the interconnection of renewable energy sources is a result of both industrial advancements and environmental concerns [4].

Microgrids are small-scale regional electric power systems within distribution networks [1]. Microgrids are gaining popularity because of their capacity to (a) diminish the impact on the environment; (b) enhance energy reliability; (c) provide ride-through capacity through electrical power storage, and (d) mitigate the adverse effects of sudden interruptions in the grid.

Renewable energy sources like wind, solar, and hydropower are low-cost to meet the requirement. In terms of power supply, microgrid technology offers rural areas substantial opportunities for increased local energy security [5]. Frequency regulation can be achieved without extra effort by connecting the microgrid powered by renewable energy to the power grid. To provide a sufficient supply of energy while meeting local demand, Microgrids are small-scale energy systems that incorporate technologies for storing and producing renewable energy [6]. Microgrids have generated a lot of interest in the electric power industry on account of their low cost, capacity to boost the power system's resilience and dependability, and impact on the use of renewable energy sources [7]. These are the most essential microgrid obstacles, such as modelling, low inertia, bidirectional power flows, stability, the impact of load perturbation, and unpredictability. However, ongoing advancements in technology and increased investment in the sector are helping to overcome these challenges [8]. Microgrid application, operation, and control systems are reviewed. The following is the outline for this paper. The microgrid's structure and operation are described in Section 2. In Section 3, the difficult process of integrating or connecting a microgrid is covered. Section 4 is about microgrid configuration and the components that influence it. The overview of microgrid control occurs in Section 5. Section 6 concludes the paper.

II. MICROGRID'S STRUCTURE AND OPERATION

Microgrids are distribution networks that have distributed energy resources—distributed generation, storage, and controlled load—that operate in a coordinated and regulated way. Fig.1 shows a typical structure microgrid [2]. Microgrids have gained much attention in the electric power industry due to their capacity for improving power system trustworthiness and resiliency, their impact on increasing the use of RES, and their reduced cost[9].

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The five main components of a microgrid structure are micro sources, also referred to as distributed generators, flexible loads, distributed energy storage devices, control systems, and point of common coupling components [1]. These elements can function in a controlled and coordinated manner in both the islanded and connected to the utility grid states. They are connected to a low-voltage distribution network. A microgrid uses a variety of renewable energy sources as its power generators [10].

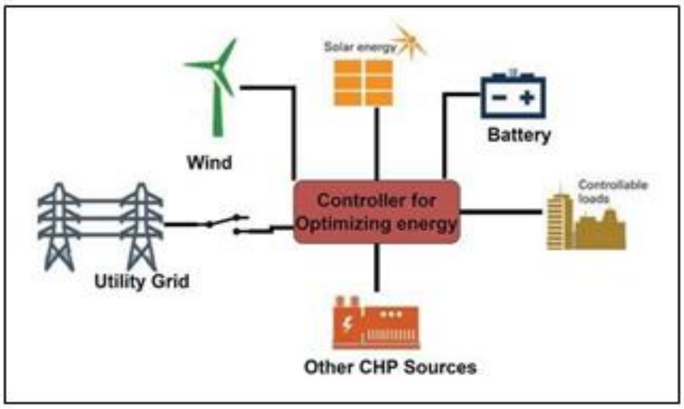

Fig1. Microgrid with Solar PV and wind as RES

Regarding the functioning of microgrids, various methods exist. A microgrid can increase the reliability of its energy supply by disconnecting from the grid in the event of a network outage or declining power quality. This is known as reconnection, transited or island, and grid-connected modes [11]. The PCC (point of common coupling) connects microgrids to the main grid; when the load is higher, the microgrid sends the energy to the grid; when the load is lower, the microgrid absorbs the excess generation through the ESS (energy storage system). [12]. When a problem occurs, the microgrid instantly disconnects from the grid and limits the demand for electricity via control methods; this is known as microgrid islanded operation. A microgrid operating in an islanded (standalone) state lacks an infinite bus, so it must independently maintain the reactive power balance [13]. Large-scale renewable energy sources, mostly solar and wind, are expected to be successfully integrated into the grid more frequently with the aid of ESS. By connecting to the AC power grid through a power electronic interface, microgrids (PV, wind, and ESS) can draw energy from the electrical grid and feed it back when it generates excess energy [14]. Extracting as much power as possible from sources while protecting it from load dynamics is the main purpose of power electronics. [15]

Power systems are typically designed larger than necessary to accommodate unexpected loads and peak demand to take into consideration unanticipated outages and weather variations [1]. Systems with a high - RES penetration will probably have larger generation capacity because of the changeable nature of the resources. Due to significant cost reductions and rising consumer demand for clean energy, wind and solar energy generation has increased dramatically over the past few decades. [4]. India currently has an installed capacity for 70.61 GW of solar power and 42.80 GW of wind power. As of August 31, 2023, India has 172.00 GW of installed renewable energy capacity [16].

III. CHALLENGES IN INTEGRATION OF MICROGRID

Numerous variables affect how well renewable energy sources perform, and these variables change over time. Consequently, the microgrid's performance is also altered, as it is dependent on how these resources operate [17]. A microgrid is a dependable and more practical method of producing electricity while using less non-renewable energy. It can enhance the stability, reliability, quality, and security of conventional distribution systems. However, there are a variety of technical and financial difficulties that could occur with microgrid integration or connotation into the main grid. Some disadvantages of the grid-connected microgrid are high transmission loss, low power quality, large investment, and voltage collapse [18].

While renewable energy systems offer many advantages, it is important to acknowledge that challenges such as intermittency, energy storage, and initial capital costs still need to be addressed for widespread adoption [19]. The uncertainties with the solar PV system are the availability of light, seasonal variation, and the characteristics of the area. The solar panel's ability to produce electricity is essentially predictable and DC varies in the solar system because of variations in sunshine intensity [20]. Controlling the main grid is difficult due to these solar systems' uncertainties and changes. Wind power generation is less predictable than solar power. Any variation in wind production fluctuates the output voltage of the wind generator, which impacts grid stability [21]. Due to these voltage variations and flickers, instability is introduced in the microgrid, which adversely affects the stability and resilience and affect the dynamic and transient responses of the system [22-23]. In wind generation transmission losses are more due to the turbine's installation away from the main grid [24]. Inverters used in converting DC to AC are responsible for harmonic issues; these harmonics affect the system [25]. Table 1 briefly explains the different integration issues and possible solutions.

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Table 1. Integration Challenges

Grid integration	***Wide-ranging challenges***	***Conceivable resolution***
Solar integration problems	Output dependent on solar irradiation and temperature, partial shading	Need a proper forecasting tool which can give an accurate prediction.
	Variability of insolation. The amount of solar energy generated depends on the amount of insolation or irradiance at any given location. Excess or less generation leads to grid instability	Development of proper DC-AC interface, with voltage and power control including MPPT.
	An inertia-less system and no reactive power support led to be challenging problem in large-scale grid integration.	Reliable design. And Online health monitoring of inverter components.
	Inverter components which result in harmonics.	Need to use compensators and proper VSC for voltage support and energy storage systems.
Wind integration problems	Synchronous operation with the grid. The effect of power imbalance results in energy loss. P-Q issues and Voltage Ride Through Capability	Selection of proper power electronic interface and controls. Active and Reactive power (P&Q) control
	Wind speed prediction.	Accurate forecasting tool and integration to power management.
	Management of the wind generation with other sources.	Manage wind generation by Connecting energy storage systems.

IV. MICROGRID CONFIGURATION AND COMPONENTS

A microgrid is a small-scale collection of electrical sources and loads that can work either alone or in tandem with the larger power grid. Usually, it consists of several components that cooperate to generate, store, distribute, and regulate the flow of electricity [26]. A microgrid's specific components can change based on its intended use, design, and local energy resources [27]. These are a few typical microgrid parts. Energy Sources, Energy Storage, Power Electronics-Inverters and converters, Microgrid Controllers, Distributed Energy Resources (DERs), Grid Connection Equipment, Load Control, and Monitoring and Communication Systems [28]. Together, these parts form a robust and adaptable energy infrastructure that can adjust to shifting circumstances, maximize energy use, and offer the neighbourhood a dependable power source [29]. The specific configuration of a microgrid depends on factors such as the energy resources available, the local energy demand, and the goals of the microgrid implementation.

Power electronic devices constitute the microgrid's critical circuit [30]. Most Microsources must be power-electronic based to ensure the flexibility required to ensure controlled functioning as a single aggregated system. Studies that will quantify the consequences of discrepancies in all the power systems' restrictions and describe their performance must be carried out. The findings from such investigations will aid in determining the precise need for the inverter [31-34]. A power electronic interface, or inverter, which are DC-AC converter, is used to connect RES to the AC power system. There are inverters available in two and three phases. While single-phase inverters are employed in low-power (15 kW) applications, three-phase inverters are employed in generating power sources [35]. However, these inverters have higher Total Harmonic Distortion (THD) and restrictions for high-power applications. recently Multilevel Inverters (MIL) have played a significant role in Microgrid applications, due to their high efficiency, and reduced cost, and the multilevel inverter output waveform is sinusoidal, which exhibits low THD without increasing the switching frequency and reduces voltage stress on the switches [33].

Table 2: Summary of Different Mil Topologies

Topology	***Aids***	***Recommended application***	***Weaknesses***
Neutral point clamped MIL	Low voltage stress in switches.	Low-frequency applications.	Unequal blocking voltage across diodes.
Flying capacitor MIL	Fault lenient capability, Modularity.	High-frequency applications.	Voltage unbalancing among the capacitors.
Cascades H-bridge MIL	High modularity, symmetry, high reliability, and fault tolerance.	Suitable for grid applications.	Complexity, cost.

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By connecting appropriately built parallel multilevel inverters for transfer from the grid and vice versa, the uncertainty in RES can be eliminated.The Microgrid requires high-quality power inverterswith low harmonic distortion to connect various power supply devices. Multilevel inverters offer the opportunity to combine hybrid systems that generate higher output power and voltage with renewable energy sources like solar and wind [32]. DC sources, control logic, symmetrical and asymmetrical topologies, THD, and switches are considered in thecomparative examination of the different topologies. Asymmetric multilevel inverter proposed in application in Microgrid with high-frequency magnetic connecting circuits, which resolves voltage level problems and THD [34]. Different MIL topologies are summarized in Table 2.

The intermittent nature of the power generated by grid-connected RES is one of its most significantproblems. The n-level cascaded H-Bridge multilevel inverter (n = 2k ±1) is one of many topologies that researchers have developed because of its quick switching and superior performance over other topologies. It is most suitable for grid integration due to its control complexity, redundancy, modularity, fault tolerance, and low cost.

V. MICROGRID CONTROL

For the prolific integration of RES, controlling the Microgrid is much more important. Inverter-based distributed generation units are becoming more prevalent in microgrid applications, necessitating the use of control techniques that deliver good performance both in balanced and imbalanced operating situations [35]. From the perspective of the customer, a microgrid is a grid system that provides dependable, self-sufficient, and high-quality electricity. Coordinating various micropower types to create a stable microgrid system that controls voltage and frequency is a difficult task [36]. The primary objectives of microgrid control are to: (a) independently control active and reactive power; (b) voltage sag and imbalances in the system; and (c) meet load dynamics specifications of the grid. In a microgrid, the three control levels are, when there is a communication breakdown, primary control is used to ensure dependable operation. Secondary is employed to control frequency and voltage based on how it reacts to variations in supply and load. The power transfer from the microgrid to the main grid is managed by the tertiary control level [1],[37]. Table 3 shows different control methods for control of the microgrid grid Additionally, a brief explanation or feature of every technique is given. Despite this, some studies review control techniques[38].

A well-designed microgrid control method considers the specific characteristics of the microgrid, the objectives of the operators, and the prevailing environmental and grid conditions [39]. It should strike a balance between maximizing the utilization of renewable energy sources, ensuring stability, and providing a reliable energy supply to the connected loads [40]. The development of a reliable decentralized control—a second-order sliding mode control—for voltage regulation in boost-based DC microgrids [41]. This control generates continuous control inputs that apply to the power converters' duty cycles, thereby constraining the microgrid state.

Table 3: Different Control Methods Of The Microgrid.

Microgrid Controlmethod	***Characteristics'***
Centralized Control [42]	A centralized control strategy involves a single master controller making decisions for the entire microgrid. The central controller gathers information from sensors distributed across the microgrid and issues commands to optimize the operation of DERs, energy storage, and loads.
Decentralized Control [43]	Decentralized control distributes decision-making to multiple controllers, with each responsible for a subset of DERs or loads. Each decentralized controller operates autonomously based on local information and communicates with neighbouring controllers as needed. Decentralized control can enhance system resilience and scalability.
Hierarchical Control [44]	Hierarchical control combines elements of both centralized and decentralized approaches. There may be a master controller responsible for high-level decisions, with lower-level controllers managing specific components or subsystems. This structure allows for a balance between global optimization and local autonomy.
Model Predictive Control (MPC) [45],[46]	MPC uses a dynamic model of the microgrid to predict its future behaviour and optimize control actions accordingly. It considers constraints and objectives over a specified prediction horizon, allowing for optimal decision-making while considering system dynamics.
Droop Control [47],	Commonly used in the control of inverters in AC microgrids, droop control adjusts the output of DERs based on frequency or voltage deviations. As the frequency or voltage deviates from the nominal value, the output of the DER is adjusted proportionally, helping to maintain system stability.
Voltage and Frequency Regulation [48]	Implement control methods, such as droop control or proportional-integral-derivative (PID) control, for maintaining voltage and frequency within acceptable. Ensure that distributed energy resources respond appropriately to deviations in voltage and frequency.
Fuzzy Logic Control [49],[50]	Utilizes fuzzy logic to handle uncertainties and imprecise information in the microgrid's operation. Fuzzy logic controllers can adapt to changing conditions and make decisions based on linguistic rules.

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An intelligent agent that interacts with other agents in a computerized system is called a multiagent system (MAS) [54]. When using a microgrid, multiagent technology focuses on controlling variables like voltage and frequency. The microgrid load changes, the grid runs out of power, and islanding is detected in the master-slave control mode sequence. The varying time scales of distinct control requirements form the foundation of the hierarchical control structure [55].

A common illustration of a centralized control scheme is the master-slave control mode [56]. To control the DC bus voltage, ESS units are regarded as the master and the other units, such as loads and renewable energy sources, are regarded as the slaves. This is known as a master-slave coordinated control mode. To ensure a seamless transition between grid-connected and isolated modes, peer-to-peer control is recommended as a means of controlling error frequency because it allows for some frequency and voltage deviation from intended values and can be readily implemented for any plug-and-play network [57]. The Hierarchy control proposed ensures stability of voltage and frequencyfor the islanded microgrid, but it requires physical communication channels; if one fails, the entire microgrid fails to operate normally [58]. But in a two-layer Hierarchy control structure, it can be overcome.

Microgrid control methods are essential for managing the various components within a microgrid and ensuring its reliable and efficient operation [59]. These control methods use advanced algorithms and technologies to optimize energy production, storage, and consumption [60-63]. Some of the modern intelligent methods that arise are artificial neural networks, fuzzy logic, genetic algorithms, partial swarm algorithms, and other hybrid intelligent techniques [64]. To optimally tune the current proportional-integral-based frequency controllers in the AC microgrid systems and control the frequency of a microgrid, an intelligent approachis created using a collection of fuzzy logic and PSO algorithms [60].

Several authors have claimed that using AI is one of the most effective ways to reduce the cost of the microgrid. Artificial Intelligence (AI) algorithms play a crucial role in optimizing the operation and management of microgrids. These algorithms leverage advanced computational techniques to enhance decision-making, improve efficiency, and adapt to dynamic conditions. the application of AI algorithms in microgrids enhances their ability to adapt to changing conditions, optimize energy management, and improve overall system performance. The choice of algorithm depends on the specific requirements, goals, and characteristicsof the microgrid.

VI. CONCLUSION

The analysis in this paper examines how to integrate renewable energy sources with contemporary power infrastructure and technology to address the challenges. It also considers the best way to include unconventional sources, potential future issues with renewable energy sources, and microgrid control techniques. An important conduit between distributed generation and renewable energy sources is the microgrid. Microgrids can function in two modes: grid-connected and islanded (self-sufficient). Compared to a regular grid, a microgrid is erratic and sporadic. Here are some illustrations of various microgrid structures along with comparative analyses of them. There is a discussion of various control schemes, includingmultilevel control schemes like hierarchical control and basic control schemes like centralized, decentralized, and distributed controls, by using different control methodologies and optimization approaches to increase the enforceability and reliability of the systems. This review study emphasizes the need for further research into the viability of microgrids and the development of environmentally friendly solutions.

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