A Comprehensive Review on Green Microgrid with Renewable Energy Sources

[1]Ankit, [2]Kuldeep Sharma, [3]Bhoop Sheoran
[1]M.Tech Scholar, [2]Assistant Professor, [3]Assistant Professor
Department of Electrical Engineering, BRCM CET Bahal, Haryana, India

Abstract

This paper presents a comprehensive review of green microgrids that incorporate renewable energy sources such as solar, wind, biomass, and small hydro power. The aim is to explore the potential benefits, challenges, and advancements in the field of green microgrids. Key topics include the design and optimization of microgrid systems, energy storage solutions, grid stability, and the economic feasibility of integrating RES into microgrids. Additionally, the review highlights the role of smart grid technologies and advanced control strategies in enhancing the performance and reliability of green microgrids. The paper concludes by discussing future trends and research directions, emphasizing the importance of continued innovation and policy support to promote the widespread adoption of green microgrids as a cornerstone of sustainable energy infrastructure.

Keywords: Hybrid energy system, green microgrid, environmental emission.

Introduction

The global energy landscape is undergoing a transformative shift, driven by the increasing demand for clean, reliable, and sustainable energy solutions. Traditional centralized power systems, primarily reliant on fossil fuels, are being reevaluated due to their environmental impact and the growing concern over climate change. In this context, green microgrids have emerged as a promising alternative, offering a decentralized approach to energy generation that leverages renewable energy sources (RES) such as solar, wind, biomass, and small hydro power [1-3]. Green microgrids are defined as localized grids that can operate independently or in conjunction with the main power grid. They integrate multiple renewable energy sources, energy storage systems, and advanced control technologies to deliver reliable and sustainable energy. The inherent flexibility of microgrids allows for the optimization of energy production and consumption, which is particularly beneficial for remote or off-grid locations where traditional energy infrastructure is either unavailable or impractical. The adoption of renewable energy within microgrid systems presents numerous advantages [4]. These include the reduction of greenhouse gas emissions, enhanced energy security, and the potential for economic savings through decreased reliance on imported fuels. Furthermore, the modular nature of microgrids facilitates the gradual integration of RES, enabling a scalable approach to energy infrastructure development. Despite these benefits, the implementation of green microgrids is not without challenges. Technical issues such as intermittency of renewable sources, grid stability, and energy storage requirements need to be addressed to ensure consistent and reliable energy supply [5-8]. Additionally, economic and regulatory barriers can impede the widespread adoption of microgrid technologies. Innovative solutions and supportive policies are crucial to overcoming these obstacles and unlocking the full potential of green microgrids. This paper aims to provide a comprehensive review of the current state of green microgrid technologies with a focus on renewable energy integration. We will examine the various components and configurations of green microgrids, assess their performance in different applications, and identify the key challenges and opportunities in this field. By analyzing recent advancements and case studies, we seek to offer insights into the practical implementation and future trends of green microgrids, contributing to the ongoing discourse on sustainable energy solutions [9]. In the subsequent sections, we will delve into the specifics of microgrid design and optimization, explore the role of energy storage systems, and discuss the impact of smart grid technologies on microgrid performance. Through this comprehensive review, we aim to highlight the critical aspects of green microgrids and their significance in the transition towards a sustainable energy future [10-13]. The escalating environmental concerns and the pressing need to combat climate change have catalyzed a global transition towards renewable energy sources (RES). Conventional fossil fuel-based power generation has been a major contributor to greenhouse gas (GHG) emissions, leading to adverse effects on global climate patterns, air quality, and public health. To address these challenges, nations worldwide are increasingly adopting renewable energy technologies as a cornerstone of their energy policies and sustainability strategies. In place of fossil fuels, renewable energy sources including biomass, wind turbines, hydroelectric power, and solar photovoltaics (PV) provide a clean, sustainable energy supply [14]. In addition to being plentiful and endless, these sources emit little to no direct emissions when in use. A key tactic for lowering the energy sector's carbon footprint and attaining long-term environmental sustainability is the incorporation of renewable energy sources into the mix of energy sources used to generate power.

HYBRID MICROGRID SYSTEM (HMS)

Combining two or more renewable energy sources, such solar and wind power, with energy storage and backup systems is known as a hybrid energy system, or HES. These systems are designed to provide reliable and efficient power generation, particularly in remote areas where grid connectivity is limited or unavailable [15]. Hybrid microgrids are small-scale energy systems that integrate multiple power generating sources, including diesel generators, wind turbines, solar photovoltaics (PV), and battery energy storage systems (BESS). These systems are made to function in both islanded and grid-connected modes, guaranteeing a steady and dependable power source. The main advantages of hybrid microgrids are higher penetration of renewable energy, less greenhouse gas emissions, and improved energy security. The economic and environmental impacts of hybrid microgrid systems are crucial factors in their planning and implementation. Studies have highlighted the trade-offs between initial investment costs, operational costs, and environmental benefits [16]. The author conducted a comprehensive economic analysis of hybrid energy systems, emphasizing the importance of considering both capital expenditure and long-term operational savings. Hybrid energy systems (HES) offer a promising solution to the growing energy demands and environmental concerns by integrating multiple renewable energy sources with conventional power generation and storage technologies. However, their implementation and optimization come with several significant challenges.

Green Microgrid

Green microgrids are a subset of microgrids that focus on integrating renewable energy sources (RES) to create sustainable, efficient, and environmentally friendly energy systems. Unlike traditional microgrids, which may combine fossil fuels and renewable sources, green microgrids prioritize maximizing the use of RES such as solar, wind, biomass, and small hydro power. This section explores the fundamental aspects of green microgrids, including their components, configurations, and the benefits and challenges associated with their implementation.

COMPONENTS OF GREEN MICROGRIDS

Renewable Energy Sources (RES):

Solar Photovoltaic (PV) Systems: These systems convert sunlight directly into electricity using semiconductor materials. They are modular, scalable, and can be deployed on rooftops, open fields, or integrated into building structures.

Wind Turbines: Wind turbines harness the kinetic energy of wind to generate electricity. They are particularly effective in regions with consistent and strong wind patterns.

Biomass Generators: Biomass generators utilize organic materials such as agricultural residues, wood chips, and biogas to produce electricity and heat through combustion or biochemical processes.

Small Hydro Power Plants: Small hydro plants exploit the energy of flowing or falling water in rivers or streams to generate electricity. They have minimal environmental impact compared to large-scale hydroelectric dams.

Energy Storage Systems (ESS):

Batteries: Batteries store excess energy produced by RES and release it during periods of low generation or high demand. Common battery technologies include lithium-ion, lead-acid, and flow batteries.

Thermal Storage: These systems store energy in the form of heat, which can be used for space heating, water heating, or power generation.

Flywheels: Flywheels store kinetic energy by spinning a rotor at high speeds and can provide short-term energy storage with rapid response times.

Power Electronics and Control Systems:

Inverters and Converters: These devices convert DC power from solar PV and battery systems to AC power compatible with the grid and load requirements.

Energy Management Systems (EMS): EMS optimize the operation of the microgrid by balancing supply and demand, coordinating the operation of RES, ESS, and conventional generators, and ensuring grid stability.

Smart Grid Technologies:

Advanced Metering Infrastructure (AMI): AMI enables real-time monitoring and control of energy consumption and generation, facilitating demand response and grid optimization.

Communication Networks: Reliable communication networks are essential for data exchange between different components of the microgrid, ensuring coordinated and efficient operation.

CONFIGURATIONS OF GREEN MICROGRIDS

Green microgrids can be configured in various ways depending on the specific requirements and constraints of the application. Common configurations include.

Grid-Connected Microgrids:

These microgrids operate in parallel with the main power grid, allowing for the exchange of electricity between the microgrid and the utility grid. They can provide ancillary services such as frequency regulation and peak shaving to the main grid while benefiting from enhanced reliability and energy security.

Off-Grid or Islanded Microgrids:

Off-grid microgrids operate independently of the main power grid, making them suitable for remote or isolated areas without grid access. They rely entirely on local generation and storage to meet energy demands, requiring robust design and management to ensure reliability and stability.

Hybrid Microgrids:

Hybrid microgrids combine elements of both grid-connected and off-grid systems. They can operate autonomously when necessary but also connect to the main grid for additional support or energy trading. This configuration provides flexibility and enhances the resilience of the energy supply.

BENEFITS OF GREEN MICROGRIDS

Environmental Sustainability: By leveraging RES, green microgrids significantly reduce greenhouse gas emissions and reliance on fossil fuels, contributing to climate change mitigation.

Energy Security and Reliability: Decentralized energy generation enhances energy security by reducing dependence on centralized power plants and long transmission lines, which are vulnerable to disruptions.

Economic Advantages: Utilizing local RES can lower energy costs, reduce fuel imports, and create local job opportunities in renewable energy sectors.

Grid Resilience and Stability: Green microgrids can provide ancillary services, support grid stability, and improve resilience against natural disasters and grid failures.

CHALLENGES OF GREEN MICROGRIDS

Intermittency of RES: The variable nature of renewable sources like solar and wind requires effective energy storage and management solutions to ensure a consistent energy supply.

Initial Investment Costs: The upfront costs for RES installations, energy storage systems, and advanced control technologies can be high, posing financial challenges for some communities and projects.

Regulatory and Policy Barriers: Supportive regulatory frameworks and policies are essential to facilitate the deployment and integration of green microgrids. Inconsistent regulations can hinder progress.

Technical Complexity: The integration and management of multiple RES, storage systems, and advanced controls require sophisticated design and operational strategies to ensure optimal performance and reliability.

Green microgrids represent a significant step towards a sustainable energy future, providing a decentralized and resilient approach to energy generation. Overcoming the associated challenges through innovative technologies, supportive policies, and continued research will be key to unlocking their full potential and achieving widespread adoption.

CONCLUSION

This comprehensive review highlights the critical aspects of green microgrids, from their components and configurations to the challenges and opportunities they present. The insights gained from recent advancements and real-world applications underscore the potential of green microgrids to transform the energy landscape. As the world moves towards a more sustainable future, green microgrids will play a pivotal role in achieving energy independence, reducing environmental impact, and promoting economic development. In conclusion, the transition to green microgrids is not only a technological imperative but also a societal and environmental necessity. By harnessing the power of renewable energy sources and embracing innovative grid technologies, green microgrids can pave the way for a sustainable and resilient energy future. Continued collaboration among researchers, policymakers, industry stakeholders, and communities will be key to realizing the full potential of green microgrids and fostering a more sustainable world.

REFERENCES

[1] Balamurugana K, Srinivasan D, Reind T. Impact of distributed generation on power distribution systems. Energy Proc 2011; 25:93–100. https://doi.org/ 10.1016/j.egypro.2012.07.057.

[2] Pepermans G, Driesen J, Haeseldonckx D, Belmans R, D W. Distributed generation: definition, benefits and issues. Energy Pol 2003; 33:787–98. https:// doi.org/10.1016/S0301-4215(03)00126-3.

[3] Jordan ′ RK, Nagy I. Power quality conditioning in distributed generation systems. In: International power electronics and motion control conference; 2007. p. 1338–42. https://doi.org/10.1109/EPEPEMC.2006.4777681.

[4] El-Samahy I, El-Saadany E. The effect of DG on power quality in a deregulated environment. In: 2005 IEEE power engineering society general meeting, vol. 3; 2005. p. 2969–76. https://doi.org/10.1109/PES.2005.1489285.

[5] Marei MI, El-Saadany EF, Salama MMA. A flexible DG interface based on a new RLS algorithm for power quality improvement. IEEE Syst J 2012;6(1):68–75. https://doi.org/10.1109/JSYST.2011.2163044.

[6] Shams Ghadamgahi AM, Hashemi Z. A review of an essential role of the distributed power generation-applications and challenges. Innovations in Energy Research 2018;7(2):1–3. https://doi.org/10.22108/isee.2018.111430.1119.

[7] Zeng C, Liu X, Fu W, Miao H, Liu Y. Power flow analysis of distribution network containing distributed generation based on sequence operation. In: International conference on power system technology towards green, efficient and smart power systems; 2014. p. 2580–4. https://doi.org/10.1109/POWERCON.2014.6993506.

[8] Funsho AM, Hizam H, Pouresmaeil E. Distributed energy resources and benefits to the environment. Renew Sustain Energy Rev 2010; 14:724–34. https://doi.org/ 10.1016/j.rser.2009.09.021.

[9] Vita V, Alimardan T, Ekonomou L. The impact of distributed generation in the distribution networks' voltage profile and energy losses. European Modelling Symposium (EMS) 2015:260–5. https://doi.org/10.1109/EMS.2015.46.

[10] Ackermann T, Andersson G, Soder L. Distributed generation: a definition. Elec Power Syst Res 2001; 57:195–204. https://doi.org/10.1016/S0378-7796(01) 00136-8.

[11] Rani P, Arora VP, Sharma NK. An overview of integration of PV system into electric grid. IOP Conf Ser Mater Sci Eng 2022 Mar;1228(1):012017.

[12] Moreno-Munoz A, De-La-Rosa JJG, Lopez-Rodriguez MA, Flores-Arias JM, Bellido-Outerino FJ, Ruiz-De-Adana M. Improvement of power quality using distributed generation. Int J Electr Power Energy Syst 2010;32(10):1069–76. https://doi.org/10.1016/j.ijepes.2010.02.006.

[13] Marei MI, El-Saadany EF, Salama MMA. A novel control algorithm for the DG interface to mitigate power quality problems. IEEE Trans Power Deliv 2004;19 (3):1384–92. https://doi.org/10.1109/TPWRD.2004.825747.

[14] Peng FZ. Editorial special issue on distributed power generation. IEEE Trans Power Electron 2004; 19:1157–8. https://doi.org/10.1109/TPEL.2004.835554.

[15] Rani P, Arora VP, Sharma NK. Control of dynamic performance through feedback converter SSC in grid integrated wind energy system. Distr Generat Alternative Energy J 2022;38(1):343–66.

[16] Haffner S, Pereira LFA, Pereira LA, Barreto LS. Multistage model for distribution expansion planning with distributed generation—Part II: numerical results. IEEE Trans Power Deliv 2008; 23:924–9. https://doi.org/10.1109/ TPWRD.2007.914704.