Integrating Micro and Smart Grid-Based Renewable Energy Sources with the National Grid in Bangladesh - A Case Study

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***Abstract*—The worldwide quest for sustainable energy solutions has led to a thorough investigation of the integration of renewable energy sources based on micro and smart grids into national electricity systems. This case study focuses on Bangladesh's particular situation, as a nation attempting to find workable solutions to its energy problems. The study explores how cutting-edge smart grid technology and decentralized energy systems, such as microgrids, can be integrated to improve the country's energy environment. The report commences by evaluating the current condition of Bangladesh's national grid, outlining the obstacles that still need to be overcome, and stressing the importance of having a variety of reliable energy sources. After that, the emphasis switches to microgrids, where their potential to support energy autonomy, harvest renewable energy locally, and lessen load on the centralized grid is examined. A thorough analysis of the technical, financial, and legal factors is carried out, considering how well micro and smart grid technologies work with the country's grid infrastructure. A case study that highlights a particular implementation in a chosen area of Bangladesh provides useful information. To assess the effectiveness and difficulties of the integration process, key metrics such the penetration of renewable energy, grid stability, and economic viability are described. In addition to providing resilience against power outages, increasing energy efficiency, and promoting a sustainable energy ecosystem, the results highlight the potential advantages of a synergistic strategy in which micro and smart networks supplement the national grid. Regulatory framework, technology standardization, and community participation challenges are all noted, and these call for the implementation of policy interventions and strategic planning. This case study provides insightful information about how Bangladesh's national system integrates renewable energy sources based on micro and smart grids. In the context of a developing nation's energy transition, it advocates for a comprehensive approach that considers technological breakthroughs, economic viability, and regulatory frameworks to unlock the full potential of decentralized and smart grid solutions.**

Keywords*—Integration, Microgrid, Smart grid, National Grid, Renewable Energy Sources

I. Introduction

Countries are forced to investigate novel approaches to improving the sustainability and dependability of their power systems as the global energy scene changes. Within this framework, integrating renewable energy sources based on micro and smart grids is a possible path toward building a more sustainable and environmentally friendly energy infrastructure [1]. This research explores the complexities of this kind of integration, concentrating on Bangladesh's particular energy problems and the possibilities for localized, decentralized energy solutions [2]. Bangladesh is confronted with noteworthy energy-related obstacles that affect both its economic progress and the welfare of its populace. The country's heavy reliance on conventional energy sources, especially natural gas, which makes up a sizable share of its energy mix, is one of the main causes for concern. The current infrastructure is under strain due to the rapid growth in energy consumption brought about by urbanization and industry. Additionally, the sporadic power supply and regular blackouts impair economic activity and lower the standard of living for the populace. Rural communities' limited access to electricity is still a major problem that impedes socioeconomic development. The nation is also under risk from climate change, as increasing sea levels endanger coastal power plants and lower the effectiveness of hydroelectric infrastructure. Financial issues that the energy sector must deal with include price subsidies and the stability of state-owned energy firms. Bangladesh is looking into renewable and alternative energy sources, making investments in wind and solar power projects, and improving energy-saving techniques in order to address these issues. Developing creative policy frameworks and international cooperation are essential to overcoming these obstacles and building a resilient and sustainable energy infrastructure for Bangladesh's future.

Like many developing countries, Bangladesh has enormous obstacles in supplying the rising demand for power while attempting to lessen its reliance on traditional fossil fuels [3]. Vulnerabilities such grid instability, energy losses, and restricted access to electricity in remote locations have been brought about by the centralization of power generation and distribution. In order to meet these issues and support international efforts to tackle climate change, it becomes essential to have a diversified energy portfolio that includes renewable sources [4]. Bangladesh's national grid is centralized, which makes it difficult to be resilient, flexible, and to maintain a steady and reasonably priced power supply in the face of changing energy sources [5]. The potential benefits of combining microgrids small-scale, community-based power systems with smart grid technologies, which improve grid intelligence, communication, and control, are becoming more widely acknowledged as a solution to these problems.

The objective of this case study is to thoroughly examine the viability and consequences of incorporating renewable energy sources based on micro and smart grids into Bangladesh's national grid. Among the particular goals are:

- To review the national grid's current condition and highlight issues.
- To know how microgrids might be used locally to harvest renewable energy.
- Explaining the integration's technological, financial, and legal facets.
- Giving a case study of an implementation in a particular Bangladeshi region.
- Reviewing the integration process's achievements and obstacles.

With the help of smart grid technologies, microgrids provide revolutionary answers to a variety of energy-related problems. Their integration improves communication, control, and grid intelligence and is essential in tackling long-standing problems that many countries, including Bangladesh, face. In order to reduce reliance on centralized networks and promote sustainability, microgrids decentralize energy generation by combining renewable sources like solar and wind. By enabling these microgrids to use machine learning, predictive analytics, and real-time monitoring, smart grid technologies enable the development of an intelligent and dynamic energy ecosystem. This improved grid intelligence solves issues with energy waste and inefficiency by enabling optimized energy distribution and demand response. The integration of smart grid technology with microgrids presents a holistic approach to addressing the diverse issues that contemporary energy systems face. These integrated systems, which offer real benefits in areas like Bangladesh that struggle with energy access, grid reliability, and environmental sustainability, greatly contribute to a more dependable, sustainable, and resilient energy infrastructure by promoting decentralization, improving intelligence, and facilitating effective communication and control.

Through its insights into the realities of integrating decentralized energy solutions into the larger national grid structure, this study adds to the body of knowledge already in existence. By concentrating on the instance of Bangladesh, the study seeks to provide recommendations that are relevant to the context and can guide policy choices, technical developments, and community involvement tactics in the quest for a sustainable energy future.

II. National Grid in Bangladesh

The national grid system of Bangladesh is essential to the country's electrical energy distribution and transmission [6]. The foundation of Bangladesh's national grid is made up of a system of high-voltage transmission lines [7]. Energy mix in national grid of Bangladesh has been shown in Fig. 1. There has been a significant shift in the energy mix used to generate electricity. Even if power produced from natural gas still dominates the national grid, this is not the situation as it was ten years ago. Natural gas accounted for 88% of installed capacity in 2008, with liquid fuel accounting for 5.9% of that amount [6]. Currently, however, gas makes up around 53% of the national grid, while liquid fuel, excluding captive generation, makes up more than 27%. The share of renewables is a pitiful 2.77%. These pipelines move electricity from power plants to distribution hubs around the nation. In order to facilitate the transformation and distribution of power at various voltage levels, substations are positioned strategically. A variety of energy sources, including hydroelectric power plants, thermal power plants that use coal and natural gas, and renewable energy sources like solar and wind, are used to supply electricity to the national grid [8]. The government frequently contracts with independent power producers (IPPs) to acquire electricity in order to guarantee a varied and dependable energy mix. The grid code of Bangladesh describes the functional and technical requirements for the country's grid [9]. It contains recommendations for safety precautions, system dependability, and grid connectivity. The national grid is operated, monitored, and balanced between supply and demand for power by a central control center [10]. There has been an attempt to improve regional energy cooperation. Energy exchange between Bangladesh and India is intended to be facilitated by interconnection projects like the India-Bangladesh electrical grid link [11]. Challenges with grid stability, variability, and the requirement for system modernization arise when renewable energy sources, including solar and wind, are integrated into the national grid [12]. Extension of the national grid infrastructure [13].

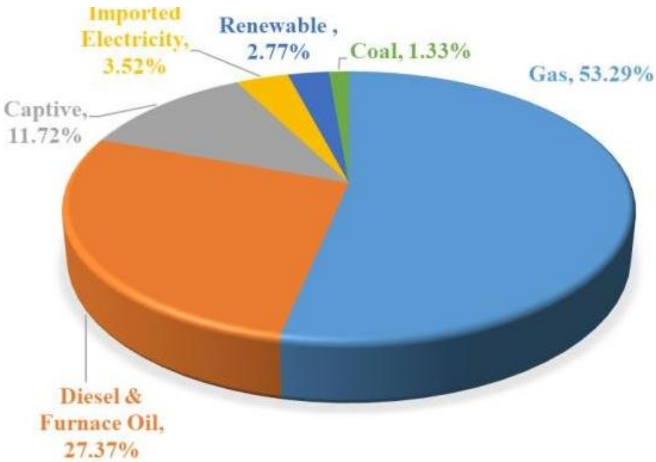

Fig. 1. Energy mix in national grid of Bangladesh [14]

In order to support renewable energy projects and resolve issues related to their grid integration, the government has taken action. Consumers in the residential, commercial, and industrial sectors receive power from the distribution network, which is linked to the national grid. To meet the rising demand for power, the government frequently makes investments in the modernization and. In order to improve grid dependability, efficiency, and the integration of sophisticated monitoring and control systems, smart grid technologies are being explored. A Power Sector Master Plan has been developed by Bangladesh to direct the growth of the energy industry, including the extension of the national grid and the installation of additional power producing capacity.

III. Microgrid

A microgrid is a small-scale, decentralized energy system that can function either separately or in tandem with the main power grid. Distributed energy resources (DERs) including energy storage devices, renewable energy sources, and other controlled loads are usually included [15]. The main objective of a microgrid is to supply a particular region, neighborhood, or establishment with dependable and resilient power, particularly in the event of an emergency or grid outage. Combined heat and power (CHP) systems, wind turbines, solar panels, and other non-renewable or renewable energy sources are common local power generating sources included in microgrids [16]. Batteries and other energy storage devices are essential parts of microgrids [17]. Advanced control systems that oversee the functioning of several components are installed in microgrids. Energy production is optimized via these control systems. Microgrid management is greatly aided by smart grid technologies [19]. Real-time monitoring and control of energy flows are made possible by advanced automation, communication networks, and metering, which raises grid efficiency overall. Microgrids are made to minimize waste and maximize energy use [20].

For example, combined heat and power systems increase total energy efficiency by capturing and using waste heat for heating. Microgrids contribute to a more resilient, sustainable, and adaptable energy infrastructure shown in Fig. 2 by helping to modernize and decentralize the power grid. They provide ways to enhance energy efficiency, dependability, and accessibility in a fast-changing energy environment. Block diagram of a smart grid technology shown in Table 1.

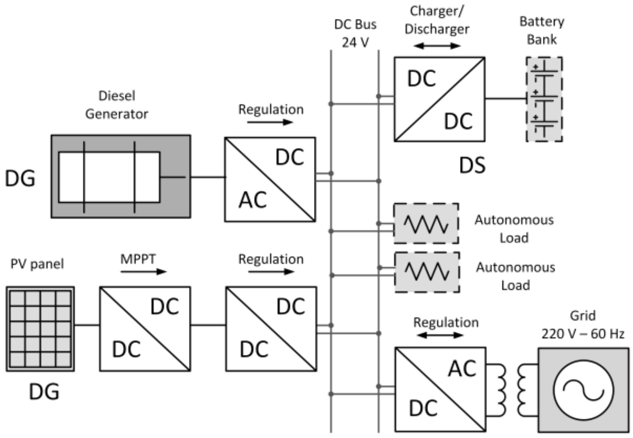

Fig. 2. Microgrid structure [18]

IV. Smart Grid

A smart grid is a more sophisticated and contemporary electrical system that uses information technology and digital communication to improve the production, distribution, and consumption of power while also increasing sustainability, dependability, and efficiency [21]. Fig. 3 shows the block diagram of a smart grid. Technology Smart grids combine many technologies to maximize energy consumption, react to variations in demand, and provide real-time communication between various grid components, with the main goal of improving the management and operation of the power system. Consumers and utility companies may communicate in both directions thanks to smart grids. Monitoring, controlling, and reacting to changes in energy supply and demand in real time are made possible by this two-way information flow. Energy-related decisions can be made by utilities and consumers alike thanks to the smart meters that smart grids install, which offer comprehensive data on energy consumption. Var control, load balancing, fault detection, and other grid functions can be automated by smart grids using sophisticated control systems [22].

Energy storage technology, including batteries, are incorporated into smart grids to store excess energy during low demand and release it during peak demand [23]. Energy storage technology, including batteries, are incorporated into smart grids to store excess energy during low demand and release it during peak demand. disruptions, smart grids improve the electrical grid's resilience. Smart grids enhance total energy efficiency by lowering losses, controlling energy flows more skillfully, and optimizing system operations [24]. In order to make traditional power networks more adaptable, flexible, and sustainable infrastructures that can tackle the problems of the twenty-first century, smart grids are essential. They facilitate the assimilation of nascent technologies and furnish a more elastic and adaptable power infrastructure. By offering real-time information and the capacity to separate and redirect electricity in the case of outages or.

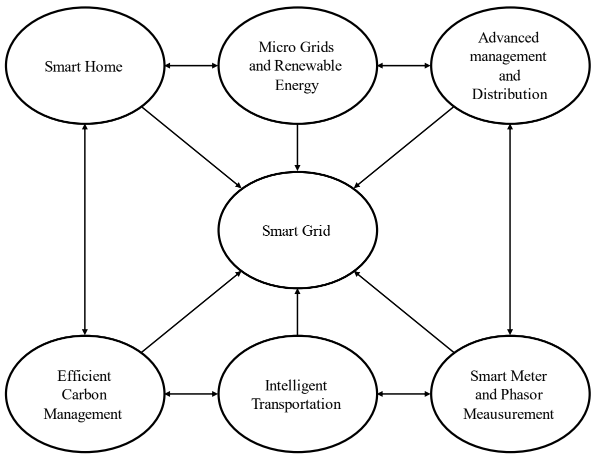

Fig. 3. Block diagram of a smart grid technology [25]

V. Challenges of Smart Microgrid

There are various obstacles to be overcome in Bangladesh when integrating micro and smart grid-based renewable energy sources with the national grid [26]. A comprehensive strategy incorporating cooperation between governmental organizations, regulatory bodies, energy utilities, and the commercial sector is needed to address these issues. An effective integration strategy must include financial incentives, community engagement, and clear policies [27]. Research and development expenditures can also aid in the discovery of creative solutions for problems relating to operations and technology. Sustainable development depends on the use of renewable energy but integrating it will take significant thought and preparation.

- Grid stability and reliability: renewable energy sources, like wind and solar power, are sporadic and weather-related [28]. The integration of these sources may result in variations in the power supply, which could impact the stability and dependability of the country's grid.

- Technical compatibility: it's possible that the dispersed and fluctuating nature of renewable energy sources is too much for the current national systems to handle. It is a technical difficulty to upgrade the grid infrastructure to handle bidirectional power flow, voltage changes, and frequency variations [29].
- Energy storage and management: since renewable energy sources are intermittent, efficient energy storage technologies are needed [30]. The effective integration of renewable energy sources into the national grid may be impeded by the lack of widely available energy storage facilities.
- Grid planning and management: thorough planning is necessary to coordinate the integration of smart and micro grids with the national grid. Complex responsibilities include managing grid congestion, optimizing grid operations, and balancing supply and demand [31].
- Regulatory and policy framework: the successful integration of renewable energy sources requires a broad framework of regulations and policies. Project developers and investors may experience uncertainty due to ambiguities or gaps in policies [32].
- Financial barriers: modernizing the grid's infrastructure, putting smart grid technology into place, and incorporating renewable energy sources can all have significant up-front expenses. Overcoming financial obstacles requires having access to investment incentives and money [33].
- Capacity building and technical expertise: personnel with expertise in renewable energy technology, smart grid deployment, and grid management are needed for the successful integration of micro and smart grids [34]. A deficiency of proficient experts may provide an obstacle.
- Cybersecurity concerns: cybersecurity risks are introduced by the use of smart grid technologies. Protecting against cyber-attacks and potential disruptions requires ensuring the security of communication networks and data [35].
- Public awareness and acceptance: it might be difficult to include local communities and get support from the general public for the incorporation of renewable energy sources [36]. It is critical to address issues with land usage, visual implications, and possible disruptions.
- Grid interconnection issues: technical interconnection problems including voltage compatibility, synchronization, and grid stability during fluctuations in power supply must be resolved in order to integrate a variety of renewable sources into the national system [37].
- Grid Infrastructure upgradation: there are situations where the incorporation of contemporary smart grid technology cannot be supported by the antiquated national grid infrastructure [38]. Although it could take a long period and large sums of money, upgrading the infrastructure is essential.

Table 1. Block diagram of a smart grid technology [25]

Criteria	Microgrid Based on Renewable Energy	Smart Grid Based on Renewable Energy
Definition	An energy system that is localized, decentralized, and runs on renewable energy sources either separately or in tandem with the main grid.	A modern electrical grid that uses digital communication, incorporates renewable energy sources, and maximizes grid performance on a broader scale.
Energy Sources	Incorporates energy storage, solar, and wind power as well as other local renewable energy sources into the microgrid.	Integrates renewable energy sources, such as solar and wind, into the grid using a combination of decentralized and centralized power.
Independence from Main Grid	May use renewable energy sources to link to the main grid or run autonomously (in a “islanded mode”).	May integrate renewable energy while maintaining a connection to the main grid, allowing for enhanced resilience during power shortages.
Primary Purpose	Emphasizes the use of renewable energy sources while providing localized, dependable electricity, particularly during emergencies or grid failures.	Increases the overall sustainability, dependability, and efficiency of the grid by integrating cutting-edge technologies with renewable energy sources.
Grid Management	Use local control systems in the microgrid to manage distributed renewable energy resources.	Uses cutting-edge control technologies to automate, monitor, and optimize grid-wide renewable energy activities in real time.
Communication Infrastructure	Depends only on internal microgrid communication; external communication requirements may be minimal.	Requires a strong bidirectional communication infrastructure in order to coordinate renewable energy sources and run the grid effectively.
Application Areas	Frequently utilized in communities that prioritize renewable energy, industrial complexes, military bases, isolated locations, and colleges.	Used with an integrative focus on renewable energy in urban, suburban, and rural areas to service greater populations and industrial complexes.
Flexibility	Emphasizes the use of renewable energy while providing flexibility and adaptation to the unique requirements of the local region it serves.	Allows for greater flexibility, taking into account a range of renewable energy sources and changing demand patterns throughout the grid.
Grid Resilience	Enhances resilience locally, as it can operate independently during grid disturbances, with a focus on resilient renewable energy systems.	Enhances overall grid resilience by responding dynamically to changes, minimizing downtime, and quickly recovering from disruptions, emphasizing resilient renewable energy integration.
Cost Implications	Initial setup costs may vary based on the scale and complexity but may be more cost-effective for localized applications with a focus on renewable energy.	Involves substantial upfront costs for advanced technologies and infrastructure but may offer long-term benefits in grid-wide efficiency with an emphasis on renewable energy.
Consumer Involvement	Often involves active community engagement and participation in decision-making, especially regarding the use of renewable energy.	Allows consumers to actively participate in demand-response programs, make informed energy choices through smart meters, and engage with renewable energy initiatives.
Environmental Impact	Generally has a positive environmental impact by promoting the use of local renewable energy sources within the microgrid.	Aims to reduce the environmental footprint of the entire electrical grid by integrating cleaner, renewable energy sources grid-wide.
Examples	Remote communities, military bases, university campuses with an emphasis on renewable energy.	Regional or national electrical grids with advanced metering systems, demand-response programs, and extensive communication infrastructure, integrating renewable energy.

VI. Discussion

A comprehensive review of the study's conclusions, interpretations, and consequences would normally be included in a paper titled Integrating Micro and Smart Grid-Based Renewable Energy Sources with the National Grid in Bangladesh [39]. This study has focused on the technological viability of merging smart and micro grids with Bangladesh's national grid. Microgrid performance has shown a great deal of potential, especially when it comes to locally sourced renewable energy [40]. Reliable electricity generation has been demonstrated by small-scale wind turbines and solar photovoltaic plants. Energy distribution efficiency has been further reviewed by the inclusion of smart grid technologies, which also contribute to grid stability through demand-response mechanisms and real-time monitoring. The energy industry undergoes a paradigm shift as a result of the integration of smart and micro grids from an economic standpoint. The long-term advantages include lower transmission losses, increased grid reliability, and possible local economic development, even though the initial setup expenditures could be difficult. Reducing reliance on conventional grid infrastructure is made possible by localized energy production, and this is especially important in Bangladesh, a nation with a diverse population and terrain.

The success of integrated micro and smart grids is greatly influenced by regulatory frameworks [41]. It is essential to have a coherent policy framework that promotes cooperation among stakeholders, expedites approval procedures, and stimulates innovation. The investigation revealed a number of difficulties, from technological uniformity to regulatory obstacles. A comprehensive strategy is needed to address these issues [42]. Creating strong regulatory frameworks that strike a balance between safety and innovation should be a top priority for policymakers. Numerous prospects for future innovation are presented by the merging of smart and micro grids. Future research should focus on developing energy storage technologies, enhancing the effectiveness of renewable energy sources, and integrating artificial intelligence to operate the grid more intelligently. A revolutionary step toward a more robust and sustainable energy future is the integration of micro and smart grid-based renewable energy sources with Bangladesh's national grid [43]. Together with economic and societal factors, the technological viability of these solutions as proven options to handle the changing energy landscape are presented in this paper. But for these programs to be successful in the long run, close attention to legislative frameworks, community engagement, and continuous technical developments will be necessary.

The government of Bangladesh has been making significant investments to upgrade and expand the country's electrical infrastructure in an effort to meet the rising demand for power. The government's Power System Master Plan (PSMP), which was created to direct the growth of the power industry, is one noteworthy initiative. To improve the capacity, effectiveness, and dependability of the national grid, a number of programs and projects are outlined in the PSMP. The transmission and distribution networks' development and enhancement are the main goals of this project. To keep up with the rising demand for power, efforts are undertaken to expand substation capacity, build new transmission lines, and renovate existing infrastructure. Based on quantitative data and particular performance indicators, the economic benefits and practical effectiveness of microgrid integration into the energy infrastructure have been shown. Millions of people now have consistent access to electricity in areas with poor access to it, like rural Bangladesh. This is a result of the installation of solar-powered microgrids.

Quantitative measures that indicate the proportion of the population now connected to these microgrids show this. In addition, the deployment of these microgrids has demonstrated a noteworthy decrease in transmission losses, as indicated by a noteworthy percentage drop in energy loss during the transportation of power across shorter distances in comparison to conventional centralized grids. Metrics showing less downtime and quicker recovery from disturbances measure the resilience and dependability of microgrids in challenging situations. For example, after extreme weather occurrences, microgrids with energy storage capacities recover more quickly. The economic advantages of microgrid projects include the generation of jobs and the expansion of the local economy; measures are used to measure the quantity of jobs created and the GDP contribution of the communities involved. Moreover, a microgrid's potential to include renewable energy sources is demonstrated by the rising proportion of renewable energy in the energy mix, which lowers carbon emissions and improves environmental sustainability.

VII. Conclusion

A viable solution to the country's changing energy landscape is the integration of smart grid and microgrid technologies with Bangladesh's national grid. By giving real-time data on patterns of energy usage, smart grids provide more effective demand-response systems. The use of smart grid technologies helps to ensure consistent power quality. With its focus on a particular geographical setting, this case study has offered insightful information about the technological, financial, and legal aspects of this integration. The study's conclusions highlight the possible advantages of utilizing smart grid and microgrid technologies to improve the sustainability and resilience of the country's energy infrastructure. Because they are decentralized, microgrids have shown they may be used locally to generate renewable energy sources, which lowers transmission losses and increases energy independence. Improved demand-response mechanism optimization, real-time monitoring, and grid management have all benefited from the addition of smart grid technologies. The path to integrated micro and smart grids is not without difficulties, though. Among the most important factors to take into account were regulatory frameworks, technical standardization, and community involvement. The combination of micro and smart grids presents Bangladesh, a country leading the way in tackling issues related to energy access, with a route to a more resilient and sustainable energy future.

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