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Empowering Bangladesh: A Study on Synergizing Renewable Energy and Smart Grid Technologies for Sustainable Development

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Abstract
This paper shows a study of the Smart Grid in Bangladesh, emphasizing the incorporation of renewable energy sources. Its aim is to provide an overview of global renewable energy demand and highlight the significance of a smart grid system in fostering sustainability and dropping CO_2emissions.The total renewable energy generation of Bangladesh stood at a meager 1.34% in 2009, representing its low comparative position with other nations. Unfortunately, there has been a little improvement over time, as the total renewable energy generation was 1.51% in 2014 and only slightly increased to 1.57% by 2019. To overcome the addressed issue, it requires massive potential of renewable energy sources to ensure a lucrative, secure, and high-quality supply. This can be achieved through effective monitoring and control mechanisms within the grid system.The integration of cutting-edge technologies such as bi-directional current flow, bi-directional communication systems, automatic working capacity, automatic control systems, and rear systems are required if the upgradation of the current power structure is needed. These advancements will contribute to the enhanced performance, reliability, and security of the renewable energy infrastructure.By embracing a smart grid system and optimizing the integration of renewable energy, Bangladesh can pave the way towards a sustainable future. This will not only boost the country's renewable energy generation but also play a vital role in mitigating CO_2 emissions.

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1. Introduction

There has been an increasing demand of electricity in global right, surpassing the capability of conventional grids to meet this mounting energy demand. Furthermore, increasing population of the earth has led to countless challenges in fulfilling the energy requirements of the grid. The smart grid (SG) is a blessing system that facilitates the link between utility providers and customers, enabling consumers to optimize their energy usage based on environmental factors, pricing, and accessibility.

Smart grids possess the ability to improve the efficiency, safety, and consistency of electricity grids. Meanwhile, a viable alternative to conventional energy sources can be the renewable energy, as it is environment friendly, beneficial for the atmosphere, and practically limitless. However, in Bangladesh, the per capita electricity production stands at a mere 510 kWh, lagging behind other Asian countries. The annual average growth rate of electricity consumption is around 6%, and per capita energy spending in Bangladesh hovers roughly 344 kilograms of oil equivalent (Kgoe). Presently, around 63% of electricity demand in Bangladesh is met through natural gas reserves.

To guarantee future energy development, spotlight will be on the development and planning of distribution systems in line with the principles of smart grid philosophy. This involves leveraging Information and Communication Technology (ICT) and pioneering control systems to enable efficient distribution processes. Additional vital aspects include active stakeholder participation, addition of renewable resources, energy storage, and the increasing number of electric vehicles.

Present years, the government and various research institutes have been working very hard to integrate renewable energy sources into the smart grid. The ultimate goal is to achieve 100% electricity generation from renewable sources. However, challenges crop up due to diverse ecological conditions and natural complexities, pose obstacles to the flawless integration of renewable energy into the smart grid system.

2. Smart Grid

By tradition, the term "grid" refers only to the interconnected transmission system, while "Smart Grid" encompasses the whole electrical system, together with generation, transmission, distribution, and even individual buildings. Also known as smart electric grid, smart power grid, intelligent grid, or Future Grid, the Smart Grid employs digital technologies to efficiently distribute power resulting in energy savings, cost reductions, improved reliability, and increased transparency.

Smart Grids improve connectivity, automation, and coordination among suppliers, consumers, and the networks responsible for long-distance transmission or local distribution. To establish a Smart Grid, there are two approaches: built it from the scratch or advancement of the existing system. While the former is challenging but feasible, the latter would require decades of gradual transformation.

A compromise option involves making short-term decisions that gradually transit existing distribution networks towards the envisioned smart prospect (Fazio *et al*., 2013).

Three main functions are being fulfilled by Smart Grid. Firstly, they upgrade the grid through automation, control, remote monitoring, and the accomplishment of microgrids and auto-recovery designs. Secondly, they inform and give power to the consumers by providing information on energy costs and enabling them to make informed choices regarding their energy usage. Thirdly, they facilitate the secure and reliable integration of renewable energy sources into the grid (Blumsack *et al*., 2015).

The existing grid system is evolving into a sophisticated network known as the Smart Grid. One of the main objectives of the Smart Grid is to ensure transition towards a lossless sustainable grid. Therefore, it will be an inverter-dominated network. However, inverter-dominated grids come with a variety of challenges. Sources of renewable energy are often discontinuous, accessible only at certain times or periods. Different RES technologies, such as solar, wind, and tidal power, have extraordinary characteristics. The storage capacity of RES is also less compared to fossil fuel-based sources and is geographically detached. The integration of inverter-connected RES into the Smart Grid is highly difficult because of these unique properties (Hassan *et al*., 2010).

A digital understanding to the grid and power utilities of the power flowing through the system is being provided by the Smart Grid. From generation to consumption, it employs smart metering techniques, automated sensors, and intelligent control systems with analytical tools to automate, monitor, and control the two-way flow of energy. Smart grids are often called as an "Energy Internet," creating a decentralized electric power system built on a standard Internet Protocol (IP) network. Smart meters, controls, and protections enable two-way communication with central grid control. The system can be built using devices and appliances supported by Home Area Networks (HAN), and data collected from HAN users can be transmitted to relevant parties for governance purposes (Bitar *et al*., 2011).

The Smart Grid relies on numerous smaller distributed power plants instead of a single large-scale plant, reducing the risk of attacks and mitigating the impact of natural disasters. In the event of an outage, the self-healing nature of the smart grid allows for quick restoration by isolating affected areas and rerouting power supply using intelligent switches and rapid digital protection mechanisms. The vast amount of data collected through advanced sensing, processing, and communication equipment aids in controlling distribution constraints and addressing challenges (Demirbaş *et al*., 2006).

While the hardware of the smart grid itself may not be revolutionary, its full integration and realization will have a transformative impact on power generation, transmission, consumption, and pricing. The inclusion of smart grid growth in energy modeling expands the range of future energy scenarios that can be evaluated (Ayadi *et al*., 2020).

Figure 1: Basic diagram of a smart grid system.

The paper by El Akhter and Biswas discusses the functions of the smart grid, and Figure 2 presents an integrated functions tree depicting these functions. The tree begins with computerized data management and progresses to the quality and efficiency of electric power transmission and renewable energy generation. At the top of the tree, we find the protection, automation, and control of power grids, along with energy system management and control (Akhter *et al*., 2016).

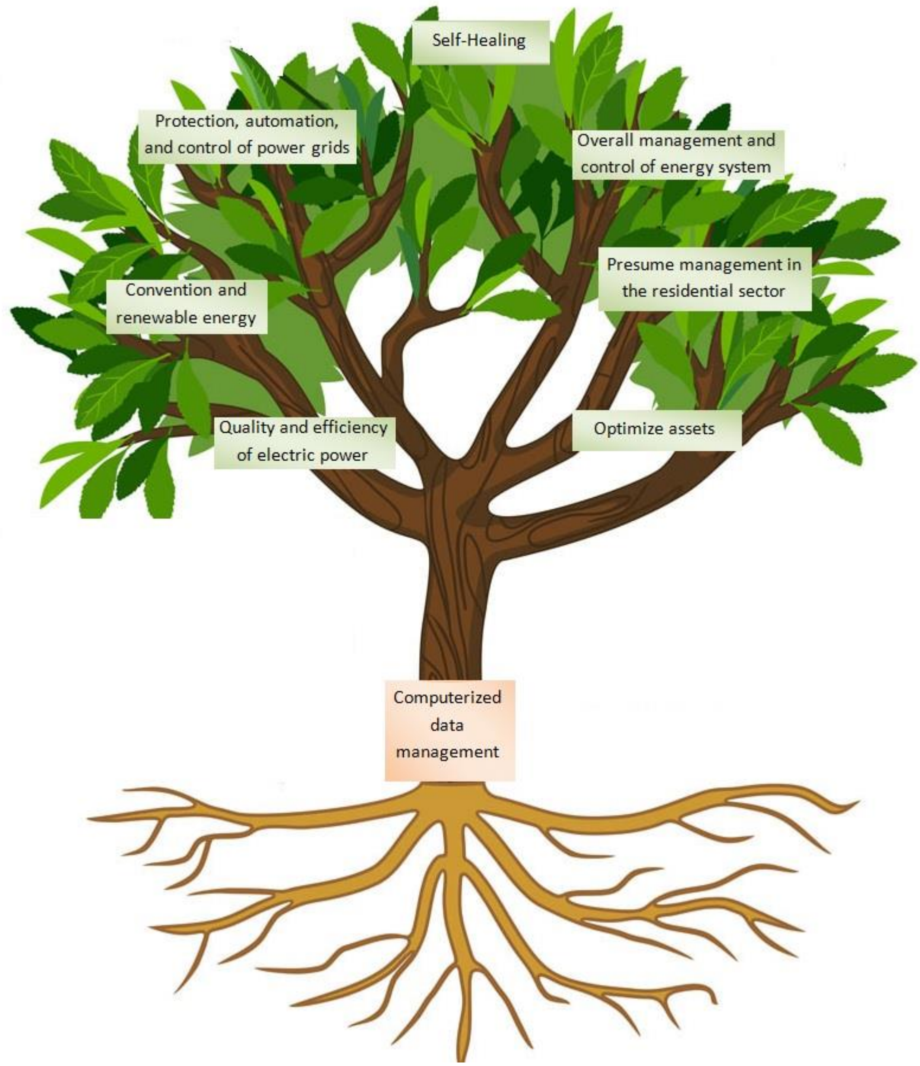

Figure 2: Integrated function tree of smart grid.

3. Renewable Energy

Renewable energy, also known as sustainable energy, is derived from naturally replenished sources such as wind, tidal, solar, geothermal, and nuclear power. In Bangladesh, solar energy plays a significant role by using photovoltaic cells in rural, hilly, and coastal areas. Wind energy is also a prominent renewable energy source in the country, with the availability of micro and mini wind energy systems (Fazio *et al*., 2013). Renewable energy is taken as a new technology that offers essential benefits other than conventional energy sources. Renewable energy systems generate minimal waste and do not require extensive cleanup. Currently, renewable energy accounts for 19% of global energy supply, with more than 30 countries already having over 20% contribution from renewable energy to their national grids. The renewable energy market is projected to experience significant growth in the coming decade.

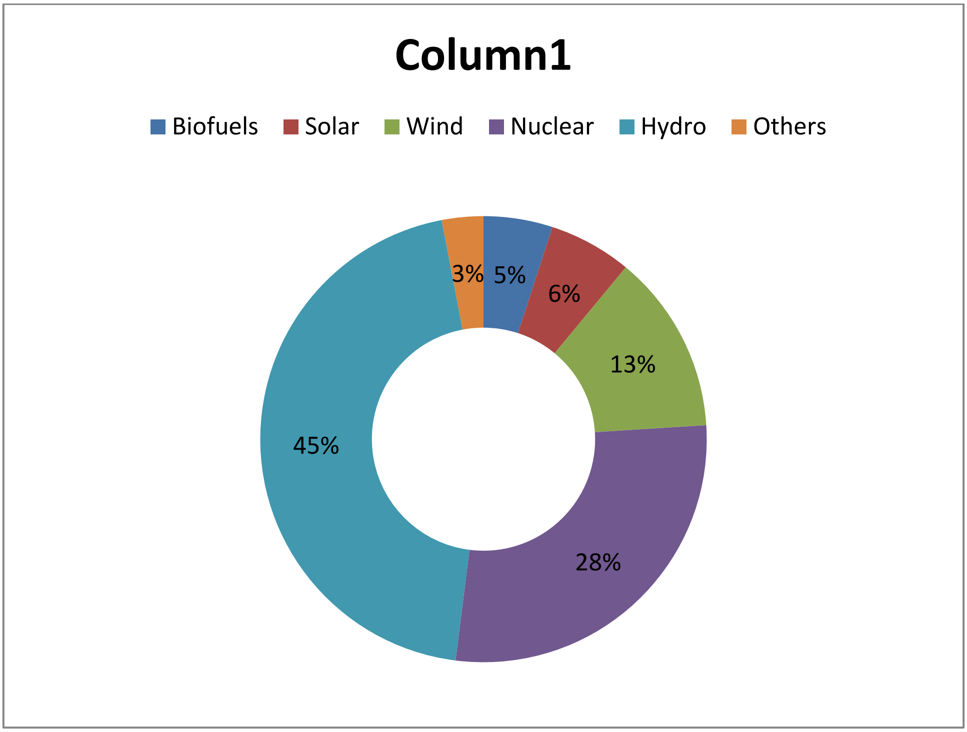

Figure 3: RE Generation Breakdown 2020.

It is a matter of concern that the contribution of renewable energy sources, which is approximately 2% to the global energy intake, is far behind in comparison to hydropower and traditional biomass whereas the later contributes nearly 18% of total energy supplies. However, there is no denial of the prudent competitiveness and prompt growth of biomass, wind, and geothermal energy (Rahbar *et al.*, 2016). The burning of fossil fuels leads to the release of almost 98% greenhouse gases around the world. To lessen the emission of carbon dioxide and other contributory pollutants, minimizing the consumption of fossil fuel would be crucial which has to be facilitated by either limiting overall energy usage or moving towards new alternatives in terms of energy sources. A good number of countries are expressing keen interest in renewable energy by ensuring their participation in collective development of new technologies. Besides, necessary infrastructural support in relation to transmission and distribution is being developed to incorporate renewable energy systems. The dominance of solar and wind power in the renewable energy sector was noticeable in 2020 with a gradual growth of hydropower. In case of the production rate in various countries, Norway tops the charts with highest rate whereas Bangladesh is on the opposite side of the chart with the lowest rate though there is a slow but steady progress.

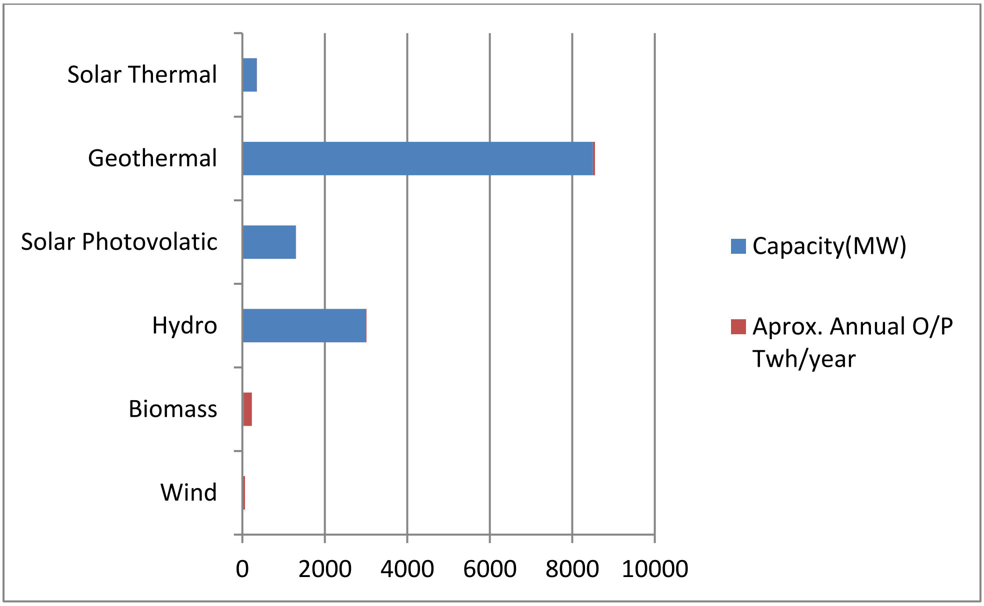

Figure 4: Global renewable energy resources.

Considering the energy requirement of mankind, renewable energy is accounted for endless source of energy as sun has more than sufficient amount of energy reserved. In current energy sector, technologies related to renewable energy have turned into more reasonable and feasible system that is ambitious enough to compete with fossil fuel technologies. The prospects like the volume and viability of renewable energy in Bangladesh namely solar energy, wind power, biomass, and biogas have not yet flourished adequately resulting in minimum progress in this field. Geographically Bangladesh is in an ideal location in terms of availing solar energy but according to the wind speed measurement report, grid-connected wind parks may be facing shortage of wind energy resources. Moreover, geothermal energy sources are inadequate in Bangladesh though various geological researches have successfully spotted the potential sites. However, considerable amount of rainfall in Bangladesh could be utilized in producing hydropower and the anticipation of the proposed hydroelectric power plants sites has already been made by the Bangladesh Power Development Board (Das *et al*., 2020).

All in all, Bangladesh promises high hopes in case of the advancement of renewable energy by facilitating the solar, wind, geothermal, and hydro resources to fulfill the demand of energy and attain sustainable and clean energy goals.

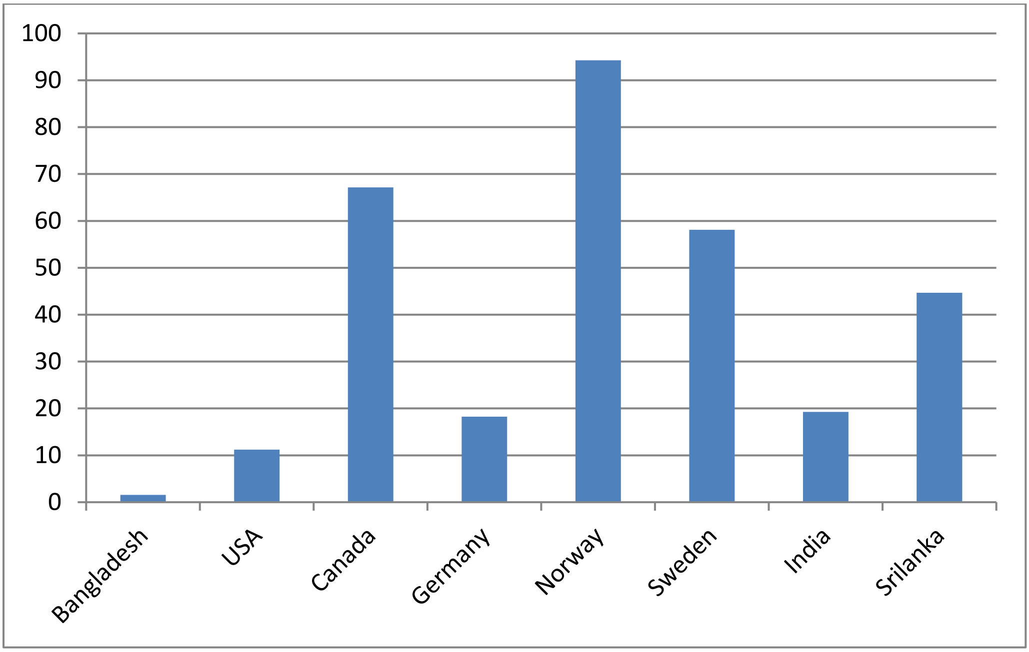

Figure 5: RE Generation Percentage in 2021.

4. Renewable Energy Integration

Modern grid systems have been advancing continuously for the last few decades. In this upgradation process, a few grid systems have proved their efficiency and workability whereas some others are relatively slow in their progress. Moreover, the disbursement of power to the communities smaller in size requires automation and micro-grid systems. Bangladesh demands the advancement of required technologies so that proper assimilation of renewable energy into the smart grid system can be ensured.

Precise estimation regarding wind and solar energy along with 200MW of supplementary hydropower would be significant for operating the grid system more consistently. For ensuring consistent operation of the grid system, the negative influences on essential spinning storage have to be controlled by the support of precise estimation that ultimately leads to low cost incorporation of renewable energy into the smart grid. Among many other sectors, wind energy estimation requires rigorous analysis and essential advancement. Two different approaches might be taken into consideration: a physical approach where numerical estimation will be incorporated with wind turbine data and strategies where time-series patterns will be investigated.

For establishing the consistency, safety and effectiveness of the grid system as a whole, the contribution of smart inverters is significant. The grid system in Bangladesh may experience consistent surveillance and adjustment facilities to reciprocate without deliberation in wide range of circumstances through the incorporation of sensor components such as magnetic sensors, pharos measurement units, infrared sensors, strain gauges, and accelerometers. One practical step to minimize the expense comparing to the traditional battery storage methods would be the conversion of electrical energy into thermal energy by utilizing energy storage appliances that consist lithium batteries and power inverters.

The integration of a number of useful devices commonly obtained from the substations like high rupturing capacity fuses, switch gears, lightning arresters, power transformers, circuit breakers, bus bars, isolators, and other items into the present transmission system would be much more cost-efficient and time-saving in the implementation process in comparison to establishing new production plants and transmission lines.

Figure 6: Integration challenges of Smart Grid.

To improve the connection between utility concerns and clients, smart meters, popularly regarded as Advanced Metering Infrastructure or two-way communicating meters, are substantial that allow simultaneous surveillance of energy consumption patterns along with some other attributes like time printing of meter data, outage reporting, on-demand requests, and bidirectional energy flow. Moreover, in this process, consumers also contribute in the grid by reinstalling energy from their very own renewable resources and support overall balancing of the load (Yusuf *et al*., 2014).

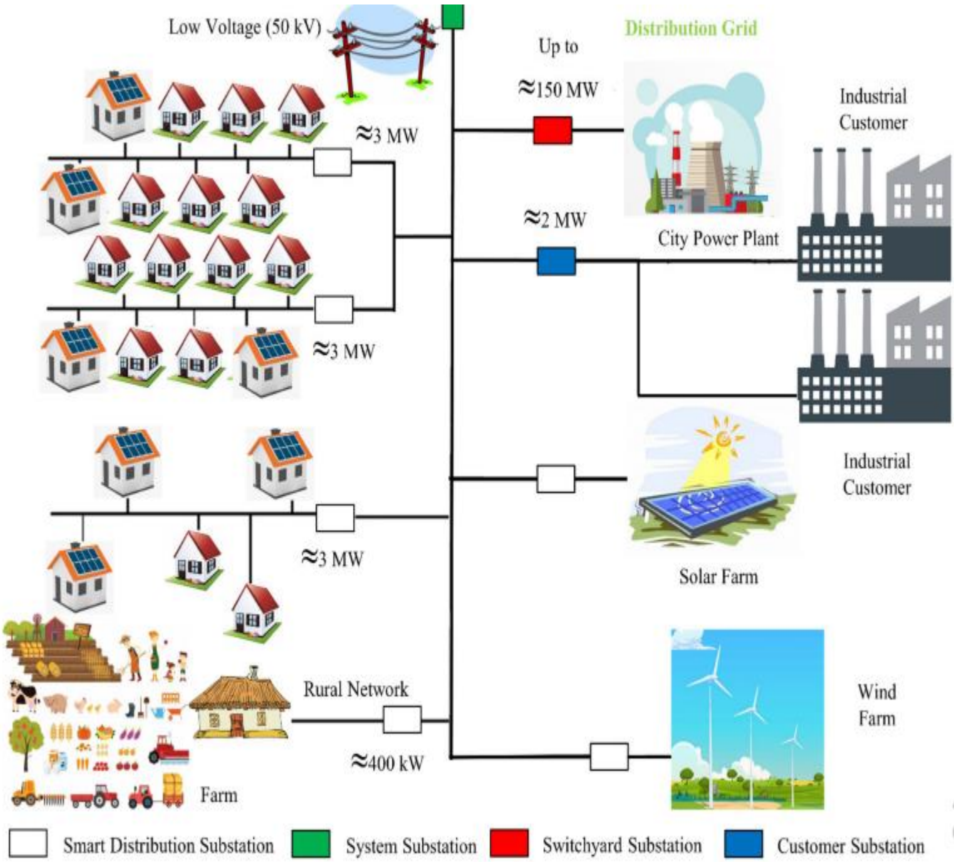

Figure 7: Integration of RE sources in smart grid and main power grid.

Customers can avail a number of systems that helps to control the distribution of electricity for service, production houses and domestic purposes through the initiation of smart grid technology into the Bangladeshi power system. Energy handling instruments, tools for storing energy, smart devices and power software for tablets and smartphones are part of these systems.

Figure 7 demonstrates how renewable energy has been incorporated to the main grid where rural solar and wind mini smart grids are linked to the power plant of city. Internet of Things (IoT) can be used to maintain and control these small smart grids. The analysis of el Abdul Hasib Siddique (Siddique *et al.*, 2021), presented in the literature section, also explained approaches of same sort which has assimilated solar energy and wind energy from domestics and wind farms respectively to the smart grid under the supervision of IoT.

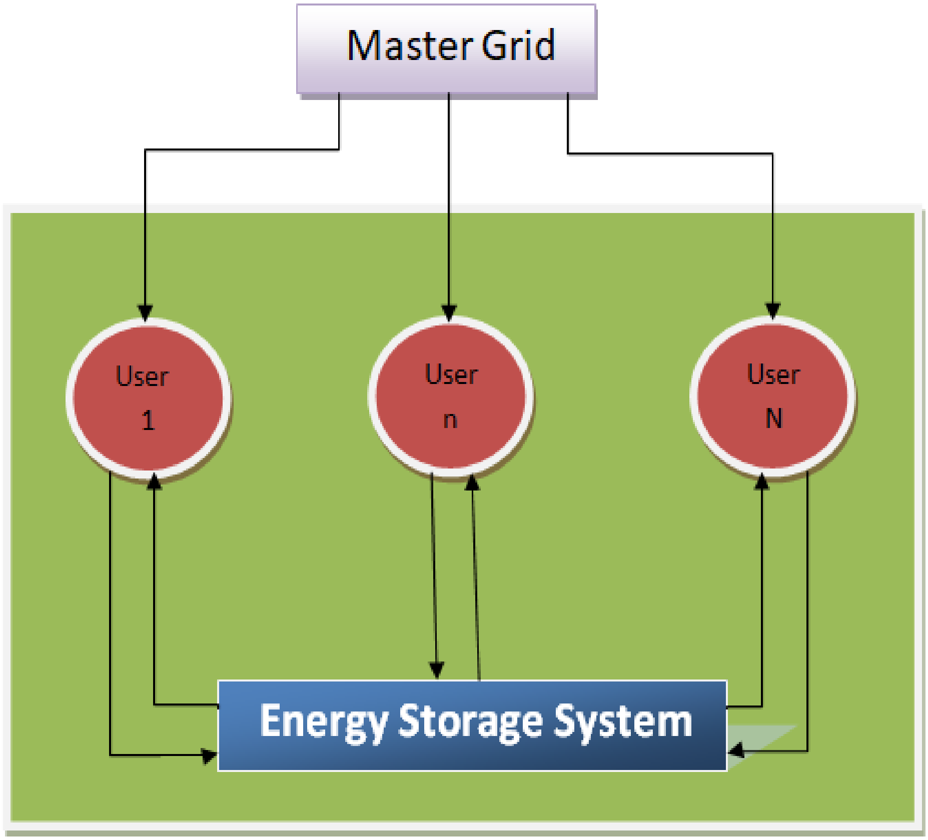

Figure 8: Shared Energy Storage System Model Diagram.

Energy storage systems, considered as essential elements of smart grids, ensure production consistency. Nevertheless, it poses a great challenge to accommodate all the energy storage systems because of the space they require in a certain zone. This problem has been attained by el Katayoun Rahbar who anticipated a collaborative energy storage management system for smart grids (Rahbar *et al.*, 2016). To enhance the charging and discharging of the collaborative energy storage system, the researchers applied an algorithm that attests individual energy storage systems inconvenient in terms of cost and space issue. A central controller of the energy storage system can be introduced to island-type smart grid systems if the former suffices the demand of all the consumers. Under these circumstances, IoT or any other methods can be used to maintain the storage system that is expected to curtail the expenses to some extent.

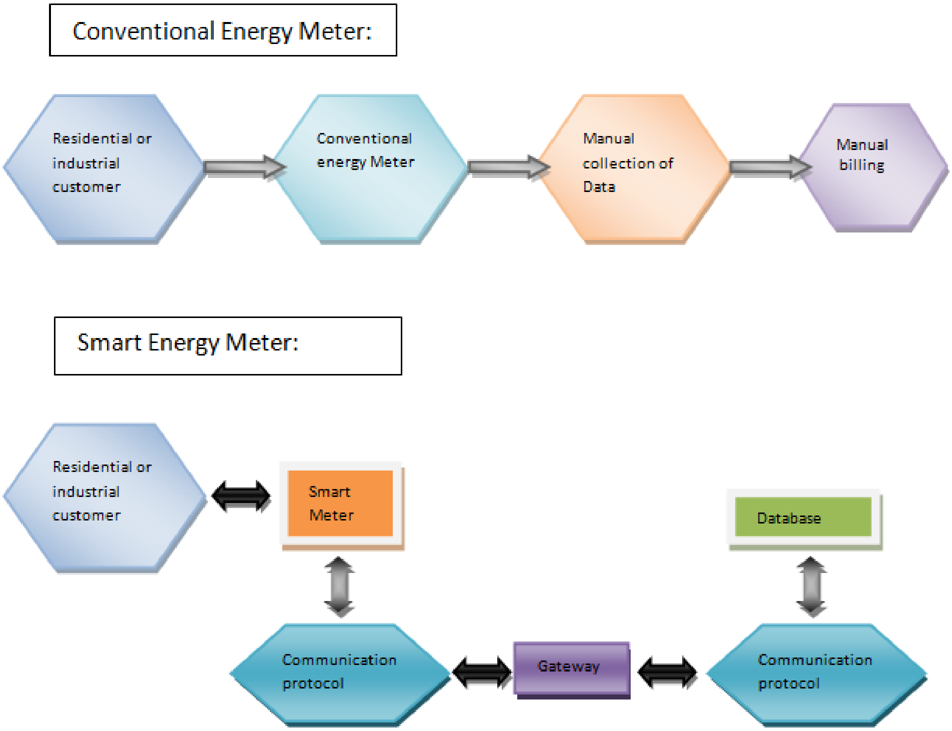

Figure 9: Smart energy meter line diagram.

For the reduction of power shortages, Muktadir Ahmed attempted a different approach by incorporating solar energy into smart grid (Ahmed *et al.*, 2015). In his article, the author initiated a kind of smart energy meter to control the supply of energy in the smart grid. The line diagram of the smart energy meter and conventional meter system has been presented in Figure 9.

In addition to the prior discussion, the adoption of renewable energy and smart grid technologies in Bangladesh faces major significant challenges and limitations. To support a large-scale renewable energy projects, the restriction in land availability is a serious threat. Furthermore, infrastructural limitations pose challenges in installing renewable energy technologies. Besides, in Bangladesh, high dependence on recurrent solar and wind energy can hamper the consistency of power generation since solar and wind energy are connected to the condition of weather. Even, the challenge gets intense with fewer possibility of necessary funding for these projects and high cost infrastructural support. Additionally, a shortage of skilled manpower and technical expertise compounds the challenge, hindering efficient installation, operation, and maintenance of renewable energy systems. Integration of these renewable sources into the existing grid infrastructure is not so easy due to varying energy generation patterns and grid stability issues. The current grid infrastructure isn't designed to accommodate smart grid technologies, making their integration a challenging endeavor. Cyber security risks loom large, demanding stringent measures to safeguard these systems against potential threats. Establishing robust communication networks nationwide presents another obstacle for efficient data management, crucial for smart grid functionality.

To tackle these myriad problems, emphasis should be placed on developing and implementing supportive policies and regulatory frameworks that encourage investment and innovation in renewable energy and smart grid technologies. Investing in training programs and educational initiatives becomes crucial to nurture a skilled workforce capable of managing these systems effectively.

5. Recommendation

At present, a number of countries worldwide are aspiring for a grand shifting of their power sectors to renewable energy. But a reassessment of the existing power grid technologies is essential for the required power transition since there is a steady growth in the production of renewable energy. A smart grid operation process in Bangladesh is demonstrated at Figure 10 (Akhter *et al*., 2016).

The process of incorporating renewable energy resources into grid systems is no doubt an arduous job but this pivotal step requires analyzing the methods of renewable energy manufacturing, preparing a suitable user guideline, confirming ideal energy use, and sorting out numerous setbacks as well as their solutions. However, solar energy is a preferred energy source in Bangladeshi setting.

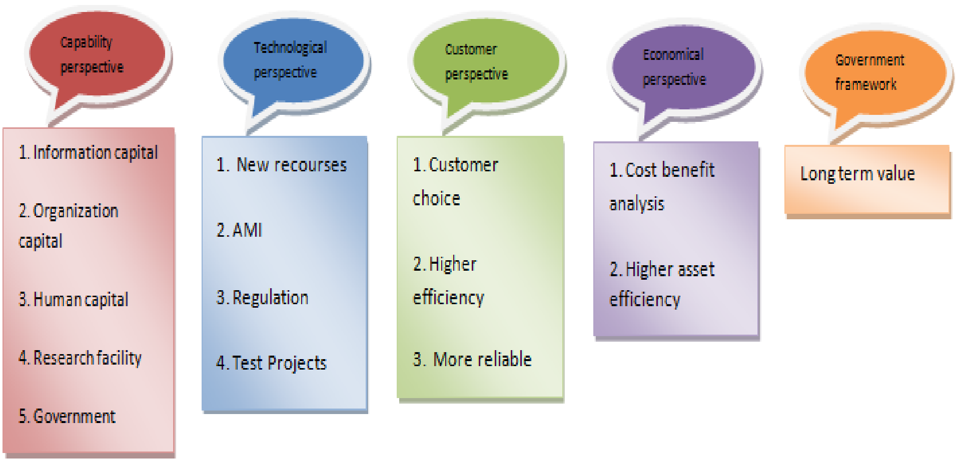

Figure 10: Pathway implementing smart grid in Bangladesh.

An agenda for long-term energy plan to sort out the upcoming shifts and challenges in manufacturing, circulating and utilizing energy has to be initiated for the effective advancement of renewable power resources and their incorporation in the national energy sector. Hence, integrating renewable energy sources into the smart grid system can be economically feasible and cost-effective in the long run although certain factors influence the overall economic viability. Considering Initial Costs vs. Long-Term Benefits, the discussion includes:

1. **Initial Investment:** The upfront costs of installing renewable energy sources (such as solar panels or wind turbines) and implementing smart grid technologies (like advanced meters, sensors, and control systems) can be high.
2. **Economies of Scale:** As technology advances and production scales up, the costs of renewable energy components have been decreasing. Similarly, smart grid technologies have seen cost reductions over time due to advancements and increased adoption.
3. **Operational and Maintenance Costs:** Renewable energy sources typically have lower operational and maintenance costs compared to traditional fossil fuel-based energy sources, reducing long-term expenses.
4. **Reduced Energy Costs:** Renewable sources often generate power at a lower cost once the infrastructure is in place, leading to cost savings compared to traditional energy sources in the long term.
5. **Energy Independence:** Utilizing local renewable resources reduces dependency on imported fossil fuels, potentially stabilizing energy prices and promoting energy security.
6. **Environmental Benefits:** The avoidance of greenhouse gas emissions and the associated environmental and health issues can have substantial economic value in the long term.
7. **Job Creation and Economic Growth:** Investments in renewable energy and smart grid technologies can create employment opportunities and stimulate economic growth in related industries.

While the initial investment for integrating renewable energy into the smart grid might be substantial, the long-term benefits, including reduced operational costs, environmental advantages, and potential economic growth, often outweigh these initial expenses. Continued advancements in technology, supportive policies, and economies of scale are key factors that can significantly improve the economic feasibility and cost-effectiveness of this integration over time.

In distant areas of Bangladesh, the lack of grid connections leads to much difficulty in electricity disbursement for firms. In those situations, diesel operated generators are used for power by the telecommunication-based firms that require proper refueling and preservation support. For electricity reserves, they are gradually relying more on solar based energy. A number of phone-based firms have initiated solar-diesel hybrid power systems that include the use of solar PV as their principal source of power alongside a generator support based on diesel.

Inclusion of photovoltaic panels alongside solar lanes would be crucial to control solar energy. Among a number of its advantages, solar lanes are capable of recharging electric vehicles instantly by means of mutual induction plates as receivers and transmitters. Supercharging stations that for example Tesla Motors employ can also avail power from solar lanes. Besides, a visual signaling system is available in solar lanes which can keep a contact with the vehicles to make it watchful from the pedestrians in road-crossing (Rahman *et al*., 2017).

Grid engineers go through a lot of difficulties in the process of incorporating variable renewable energy (VRE) as VRE resources has specific features like variability and low predictability, and very particular applications they will be the part of. Current flexibility in terms of resources and the necessary power supply standard determine the difficulty faced in incorporation process and other relevant expenses of VRE. Power based organizations require delivering ancillary support to minimize the possible hazards and interruption offered by VRE if they want to ensure better consistency and power standard in systems. Even productivity may need to be compromised due to expenses of load loss or impaired machineries. In addition, the energy needs to be transmitted via extensive transmission lines depending on voltage levels as a good number of renewable energy centers

Another setback in the widespread adoption of renewable energy and smart grid technologies in Bangladesh has also been facing significant social and cultural hurdles. Limited awareness among the public about these technologies hampers acceptance, necessitating educational outreach programs to highlight their benefits and functionalities. Moreover, doubts persist regarding the reliability of renewable energy sources compared to traditional fuels, contributing to skepticism about their consistent power generation. Besides, affordability poses a substantial barrier, with initial installation costs for these technologies perceived as unattainable for many households and businesses. Unequal access to technology, especially in rural or underprivileged areas, further inhibits their adoption. Cultural resistance to change, rooted in ingrained energy usage habits and the cultural significance of land, presents challenges. Convincing communities to transition from conventional to renewable energy sources encounters resistance due to these deeply embedded habits and values. Integrating modern smart grid technologies into existing infrastructure encounters compatibility issues and the need for extensive upgrades. Moreover, insufficient community involvement during planning and implementation phases can lead to local opposition. To overcome these barriers, engagement through education and workshops is essential to dispel misconceptions and improve acceptance. Tailoring renewable energy projects to fit local needs and cultural contexts can demonstrate relevance and respect for cultural values, enhancing acceptance. Supportive policies addressing affordability and access, coupled with public-private partnerships, can encourage investment and deployment of these technologies while considering cultural sensitivities. Bridging these social and cultural gaps through education, community involvement, and supportive policies is pivotal for the successful integration and widespread acceptance of renewable energy and smart grid technologies in Bangladesh. These efforts can pave the way for smoother implementation and long-term acceptance.

However, Bangladesh can certainly avail a better prospect through more insightful measures and attaining sustainable energy goals if the associated challenges are taken care of properly.

6. Conclusion

The contribution of renewable energy (RE) technologies will surely be immense in the upcoming development of Bangladesh which is accelerated by their capital expenditure being almost similar to grid electricity. At present, a huge portion of produced electricity, approximately 80%, are based on natural gas treasury that does not mean to support the production more than coming 15 to 20 years. Nevertheless, renewable energy sources contribute only 2% of the total electricity produced that necessitates immediate incorporation of smart grid (SG) technologies by attaining technological development in Bangladesh.

In this article, renewable energy sources have been highlighted with all of their benefits that consist of improved energy safety, socio-economic progress, ensuring climate policy requirements and limiting environmental and health effects. Though there are a good number of positives of renewable energy sources, a few barriers are still there to deter their long-lasting feasibility and capacity to face climate change. Among many crucial setbacks, market collapse, inadequate responsiveness, insufficient flow of raw materials in case of further renewable resource management and very significantly, inconsiderate energy usage are notable. For encouraging human advancement, reinforcing economic efficiency and reenergizing all inclusive progress, there is no alternative to energy. Therefore, accepting renewable resources to resolve climate change issue can be appreciated if they are considered from long-standing viewpoints to guarantee a sustainable economy that can attain the energy requirements of the upcoming generations controlling the environmental and health effects.

The integration of renewable energy sources and smart grid technologies brings substantial environmental benefits. Utilizing solar, wind, and hydroelectric power reduces greenhouse gas emissions, aids climate change mitigation, and enhances air quality. Relying on infinite resources, these technologies reduce dependence on finite fossil fuels, curbing resource depletion and minimizing ecosystem impact, preserving biodiversity and lowering habitat destruction. Moreover, their minimal waste production contributes to a cleaner environment compared to fossil fuel-based power generation. Achieving sustainability during this transition requires holistic assessments, ensuring environmentally conscious practices across manufacturing, installation, and decommissioning. Meticulous planning minimizes ecological disruptions from large-scale deployment, while responsible material sourcing supports eco-friendly practices. Additionally, integrating smart grid technologies enhances energy efficiency, grid stability, and energy distribution, contributing to an overall more sustainable energy infrastructure.

Various technical options need to be analyzed in order to support the assimilation of variable renewable energy (VRE) into the power grid. The options comprise system-favorable VREs, adjustable manufacture, grid extension, sustainable energy technologies, and reserve systems. Production adaptability has to be attuned in the energy sources to enhance outcome from not only dispatchable resources but also non-dispatchable resources. Since traditional power generation is highly expensive, stakeholders are more commercially attracted to VREs and grid integration technologies. Applying these technologies is capable of improving the power system with better consistency, effectiveness and overall activities. So, concerned officials need to design an all-inclusive framework for RE grid incorporation depending on the current system features, upcoming technological facilities and long-standing objectives as technology has been growing very fast and a number of grid assimilation opportunities are very much within reach.

The adoption of prospective renewable energy sources, integration of smart grid technologies and addressing possible limitations can accelerate sustainability and affluence in Bangladesh. Apart from overcoming the climate change issue, the inclusion of renewable energy into the power division will facilitate economic development, assure energy safety and fulfill the upcoming energy requirements of the country.

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Conflict of interest

The authors affirm tht there are no confilics of interest associated with the publication of this work. They have followed ethical guidelines and addressed various issues; including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and and/or submission, and redundancy. The authors have thoroughly observed and complied with ethical standards throughout the research and writing process.

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