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REVIEW

Prospects and challenges of renewable energy-based microgrid system in Bangladesh: a comprehensive review

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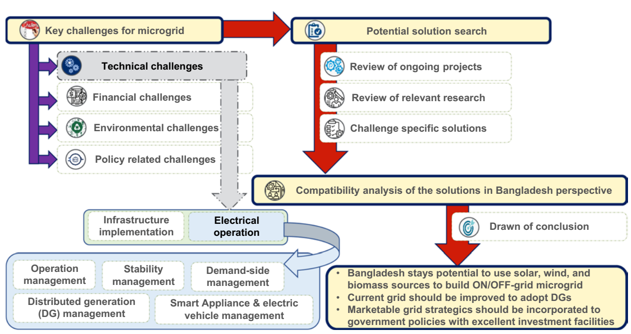
Abstract
Global energy demand is continuously increasing where the pollution and harmful greenhouse gases that originated from the burning of fossil fuels are alarming. Various policies, targets, and strategies are being set to the carbon footprint. Renewable energy penetration into the utility grid, as well as bidirectional power flow between generation and end-users, are also potentials. A microgrid energy system can help distribute energy from intermittent renewable generation centres to load centres more effectively. The microgrid system efficiently utilises electricity from renewable sources, such as solar, wind, hydro, geothermal, and biomass. The potential renewable transition opens up a lot of possibilities for microgrids that are both grid-connected and islanded. Digital technology, specialised energy measurement devices, a fast and efficient communication system, energy storage systems, and dynamic control techniques are all used. The renewable-based microgrid system faces numerous techno-economical vulnerabilities due to the volatile and environmental dependencies of renewable energy. The complex power converter stages, lack of strict regulatory rules, grid operations and management, communications between the centralised and decentralised controllers come into play while investigating the microgrid system. This paper focuses on the prospects of renewable-based microgrid system implementation in Bangladesh. The major challenges and solutions to those challenges are described with all the current breakthroughs across the world to solve some core issues regarding microgrid planning, controlling, maintenance, resilience, and economics.

Graphical abstract



Keywords Energy · Renewable energy · Microgrid · Power demand · Generation · Distribution

Introduction

Energy is one of the basic input and vital building blocks of national development, where the energy comes from both renewable and non-renewable sources. Electricity is one of the most useable forms of energy, where electricity is produced mostly from non-renewable sources, such as coal,

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oil, and natural gas. According to the International Energy Agency (IEA) estimation, in 2018, the world's total energy supply was 26,730 TWh (IEA 2021). The non-renewable sources contributed as: 10,159.6 TWh from coal energy, 6150.2 TWh from natural gas, 2710.4 TWh from nuclear reactors, and 783.7 TWh from oil sources. The combustion of the non-renewables yields a severe environmental impact of carbon footprint, acid rain, rifting ozone layer, and temperature rise (Hasanuzzaman et al. 2017). As a result, renewable energy sources (i.e., solar, wind, biogas, biofuel, hydro, geothermal, biomass, etc.) are the potential resources to mitigate climate change and environmental issues (Malek et al. 2020). During 2018, a total of 6811 TWh of energy are produced from renewable sources, consisting of 4325.1 TWh from hydro, 1273.4 TWh of wind energy, 554.3 TWh of solar energy, 518.4 TWh of biofuel, and others (IEA 2021). Unlike the high voltage, long-range power transmission of the traditional system, which unavoidably raises transmission losses, the power from distributed renewable resources (DRs) is reliable, clean, and affordable. Researchers have introduced mini-grid, microgrid, and smart grid (SG) schemes. The idea is to produce renewable energy to meet the peak load since many are intermittent and use non-renewable plants for base load compliance (Islam et al. 2014). A case study with 61 kW Mashhad Sarrood power house has revealed that augmentation of the power plants gross production with solar and wind plants power outputs during the hot and dry season can drastically alleviate the problem of seasonal power production fluctuation coming from running rivers near the rural areas (Hoseinzadeh et al. 2020a, b). When side mirrors and sun-tracking technologies are embedded in the solar energy conversion systems, the overall conversion efficiency increases with making the system more economical to operate. In recent times, the geothermal energy-based ground-source energy with cold recovery is continuously being investigated for heating and cooling of households, purifying and desalinating drinking waters, and producing electricity (Mahmoudan et al. 2021). Geothermal energy can also back the power required to carry out the reverse osmosis process of water desalination, usually integrated with the carbon dioxide power cycle. Such a setting could reduce the cost of freshwater production by 10% (Hoseinzadeh et al. 2020a, b). Thus, the potentiality of renewable-based system is yet to be flourish and diverse. Carefully scrutinised plans could result in efficient initiation of an energy-producing plant based on the availability of potential natural renewable sources, load demand around the plant's area, reduction of carbon dioxide emission, and the economics during the process (Sohani et al. 2021).

Bangladesh, a developing country in the Bay of Bengal, is a land of vehement versatility. Currently, the country's single nation grid contains energy generated from the public (49.6%) and private (44.7%) sectors and by importing electrical power from the neighbouring country India (5.9%) (BER 2021). As of 2020, the total installed capacity of the national grid of Bangladesh is 22,787 MW. According to the Bangladesh Power Development Board's (BPDB) report, in July 2020, electricity had reached the country's 96% of the population (BPDB 2021). Due to the high population density, the energy demand is tremendously increasing. From 2009 to 2020, the per capita electrical energy consumption increased from 165.3 to 374.6 kWh. It is predicted that, in 2030, Bangladesh will need 34,000 MW of power to sustain its economic growth by around 7%. In 2016, the government made Power System Master Plan (PSMP) by setting a goal for installation capacity to 24,000 MW by 2021, 40,000 MW by 2030, and 60,000 MW by 2041. The largest power plant in the country, the Rooppur Nuclear Power Plant, with 2400 MW of capacity that is expected to be operated by 2023. Currently, the power generation from renewables (1.5% of total generation) is focused on solar photovoltaics (PVs) energy (70 MW) and hydro energy (230 MW). The country could be booming in renewable energy generation due to its fantastic geography, which involves the coastal region, hilly areas, hot summers, and mild winters.

The country has already launched the '500 MW Solar Power Mission' to accolade renewable use culture. Different investigations have been conducted to see the prospect of renewable energy and found that Bangladesh can boost its renewable generation and carbon footprint reduction by pertaining production from biomass, solar, hydro, wind, and tidal energies. During dispatch of non-renewable energies, developing countries like Bangladesh face major challenges due to the high initial investment, operation and maintenance costs, regulatory barriers, and maintaining carbon emission.

Furthermore, the favourable locations of renewable sources often exist at far distances from the localities. Renewable-based microgrid development can be beneficial from a socio-economical perspective. Microgrid system can initiate islanded erection of sustainable irrigation systems and be applied to military applications, hospitals, solar home systems (SHS), PV street lighting, electric vehicle charging stations, and many more (Elkadeem et al. 2019) by transferring electric power from potential sites to islanded load centres. A renewable-based microgrid is an electrical distribution system that consists of a cluster of loads and DGs that generate electricity using renewable resources. The microgrid is a compromise between the traditional large generation and individual renewable generation systems. The traditional large generating plant mostly uses non-renewable sources that hamper both the environment and human health. On the other hand, the individual distributed generation structure suffers from high capital costs, voltage fluctuation, thermal limit of certain lines and transformer often exceeds the normal operating range, islanding problem and local generation-demand mismatch (Mohamed et al. 2017). When the traditional UG is connected to the DGs by proper point of common coupling (PCC), benefits such as enhanced local reliability, better local voltage support, reduction GHGs, reduced feeder loss and voltage sag, controllable loads, efficient and uninterruptible power availability (Kabel and Bassim 2020). The consumer-end DGs often are augmented with storage devices, controllable loads, and use power electronic interfaces (PEIs) and control to maintain power quality and energy output flexibly. However, the microgrid implementation till now is in the immature phase. Microgrid operation requires perfection on the horizon of stability, reliability, economics, and cybersecurity, requiring overcoming technical, regulatory, financial, and stakeholder-related barriers in Bangladesh. Being a developing country with limited economic stability, skilled manpower, and natural resources, Bangladesh is still in the nascent stage of developing the technical standards and rules, financial incentives and market policies, and regulatory policies that are crucial while planning for the establishment of a renewable-based microgrid system for the first time in large scale. Researches have proposed various practical architecture approaches, but the research related to microgrid implementation in terms of reliability and stability does not suffice. Thus, along with the microgrid's prospect, a need clear understanding of how it can be useful for overcoming various challenges while implementing the microgrid in Bangladesh.

Therefore, this paper proposes the prospects, challenges, and potential suggestions to overcome the drawbacks during the planning, implementation, and commission of a renewable energy-based microgrid in Bangladesh. The work tries to sort out the solutions, alternatives, and initiatives that are essential for a microgrid system to overcome the barriers that exist. As such, this work will be helpful for researchers, legislators, and policymakers involved with these technologies; and institutions and organisations who are trying to establish the viability of technologies.

Prospects of renewable energy-based microgrid

Bangladesh is one of the rapidly growing developing countries in the world. Due to its geographical position on the Bay of Bengal's seabed, the country faces many natural vulnerabilities now and then. The power system can seldom comply with the increasing amount of load demand during the presence or absence of any disaster. The country's government is trying to include renewable and sustainable energy technologies to improve its electrical energy footprint and cut off carbon emissions. According to Nationally Distribution Contribution (NDC) in the 2018 report, the amount of carbon emission from the power, transport, and industrial sectors is predicted to be 63% of Bangladesh's total carbon emission. Thus, looking for sustainable power and energy sources is a must for the country. Sustainable and Renewable Energy Development Authority (SREDA) of Bangladesh initiates plans, policies, and dispatch of renewable practices and has urged improving total generation from the renewables. The current installed power capacity dwindles around 21,000 MW (BPDB 2021). Figure 1 shows the installed power generation capacity of Bangladesh from 1970 to 2019 (Chowdhury 2020). From the figure, it can be seen that the country's power generation accelerated after 2010. During 2010–2019, the installed capacity increased almost three times. The fuel-wise generation is provided in Fig. 2 (Chowdhury 2020). The majority of the power generation units use natural oil, coal, heavy oil, and other conventional non-renewable resources. The percentage contribution of hydro energy to the total capacity has decreased vastly. From Fig. 2, it can also be noticed that the contribution of natural oil is decreasing due to the lack of abundant natural gas resources and fast exploitation of the present

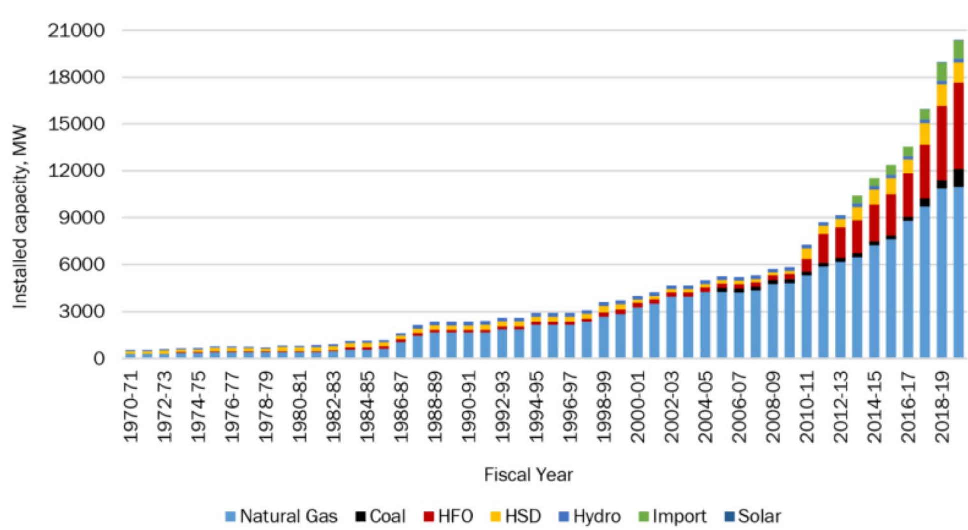


Fig. 1 Installed power generation capacity of Bangladesh from 1970 to 2019 (Here, HFO and HSD refer to Heavy Fuel Oil and High-Speed Diesel, respectively) (Chowdhury 2020)

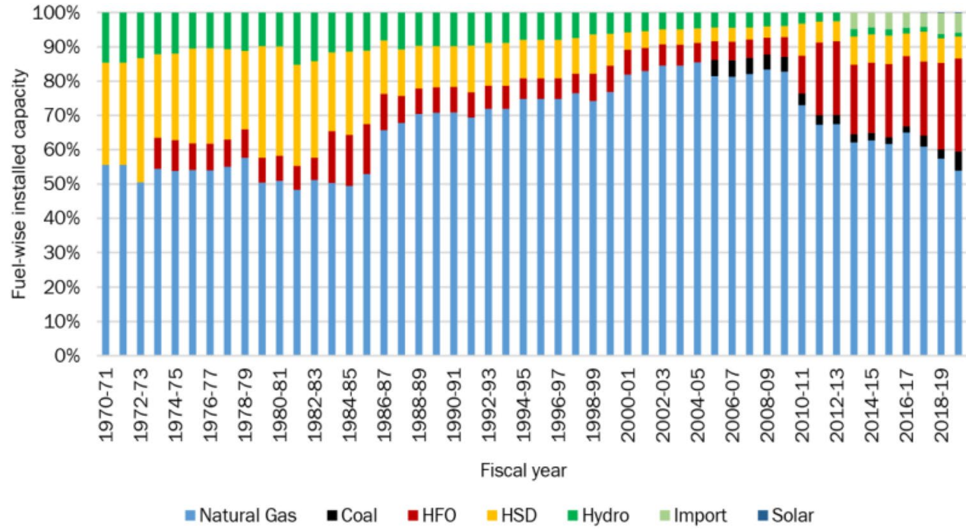


Fig. 2 Installed power generation capacity by fuel sources of Bangladesh (Here, HFO and HSD refer to Heavy Fuel Oil and High-Speed Diesel, respectively) (Chowdhury 2020)

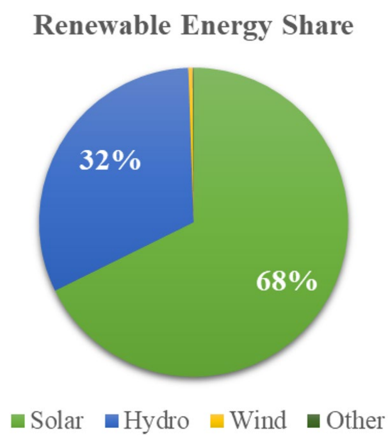


Fig. 3 Renewable energy-based power generation in Bangladesh, 2021 (REGM 2021)

Table 1 Installed renewable energy capacity by sources in Bangladesh, 2021 (REGM, 2021)

Technology	Off-grid (MW)	On-grid (MW)	Total (MW)
Solar	346.19	142.02	488.2
Wind	2	0.9	2.9
Hydro	0	230	230
Biogas to electricity	0.63	0	0.63
Biomass to electricity	0.4	0	0.4
Total	349.22	372.92	722.13

sources. The power generation needs to increase in a fast and environmentally friendly manner where the potential renewable resources are solar, biomass and biogas, wind, hydro, and geothermal. In 2021, the renewable generation of Bangladesh is depicted in Fig. 3 (REGM 2021). According to Table 1, in 2021, both solar and wind contribute significantly. However, the biomass and biogas plants could share a sheer amount of energy if deployed systematically across the country. The sun impinges on the surface of Bangladesh with a moderate energy potential of 4.5 kWh/m^2. This energy can be converted to electrical energy via solar-thermal power plants or solar-PV routes. Solar PV can be implemented in a much economical and easier fashion. The geographic distribution of solar energy potential is mapped by the ESMAP and is shown in Fig. 4 (ESMAP 2021). The maximum power potential area is the south-eastern part (including the Kaptai lake area) of the Chittagong division, which can produce power as much as 4.3 kWh/kWp due to its hilly terrain. However, the southern parts (especially near the Meghna estuary region) of the country, though they come with moderate solar PV power potential, are the best to deploy large-scale solar PV plants near the load centre and economical operation. The Government of Bangladesh (GOB) has initiated different solar power plants across the country. According to SREDA, the second promising renewable energy source in Bangladesh is bio-fuels (biomass and biogas). Sources including firewood, fermented tree, crop residue to animal waste, municipal waste, and others are abundant in Bangladesh.

The third most resourceful renewable source for Bangladesh is wind energy. In Table 2, different potential areas and their relevant wind speed velocities are summarised (Hossain and Ahmed 2013). Different organisations took the study place at different year spans. In 2018, in support of the United States Agency for International Development (USAID), a study comprising of Power Division, Ministry of Power, Energy and Mineral Resources (MPEMR), Bangladesh, and the National Renewable Energy Lab (NREL), USA demonstrated that for wind speed range 5.75–7.75 ms^{-1}, there are about 20,000 km^2 of potential land-based wind

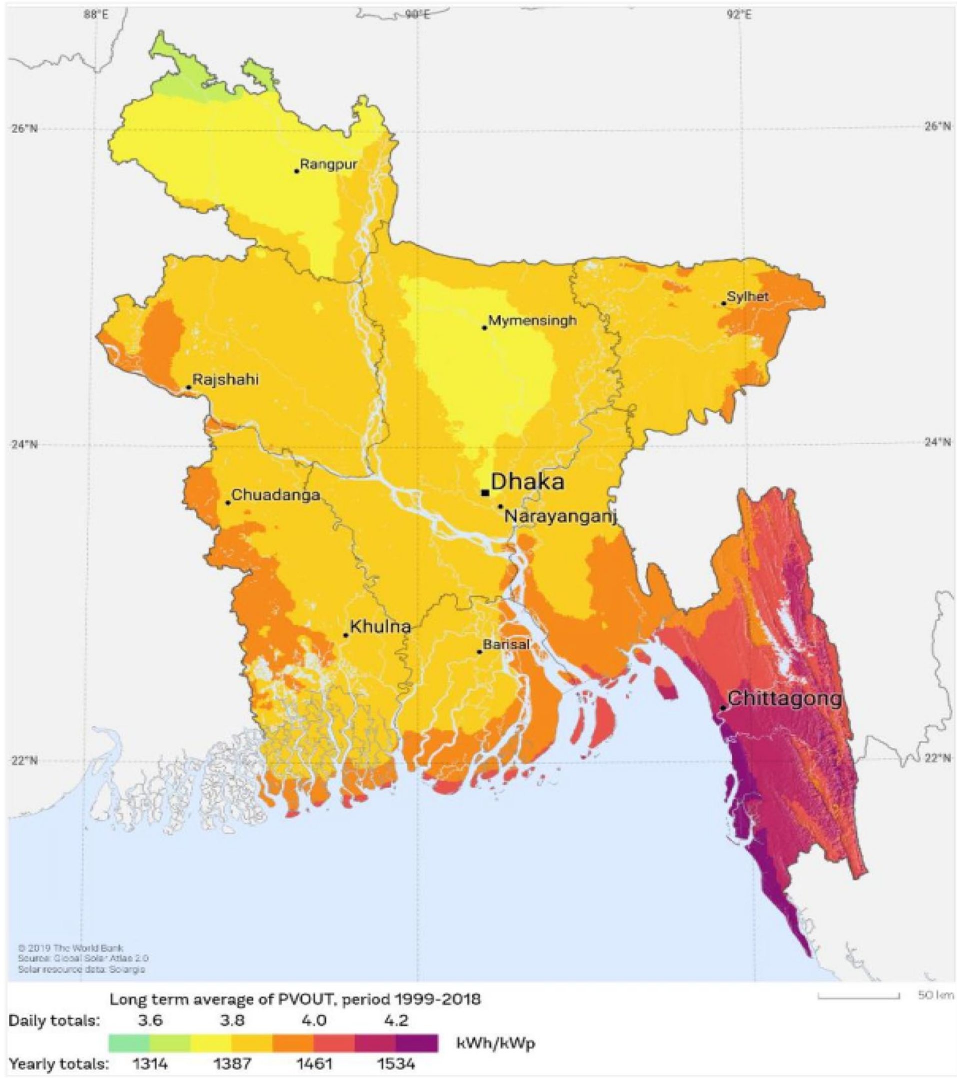


Fig. 4 Solar photovoltaic power potential across Bangladesh (ESMAP 2021)

energy area that can produce more than 30,000 MW of energy (Jacobson et al. 2018).

The study concludes by describing the very limited mini-hydro and micro-hydro potentials on the Matamuhuri, Sangu. There are a few potential temperature gradients in Bangladesh in its earth core across the regions Titas, Habiganj, Hazipur, Rashidpur, Biani Bazar, Bakhrabad, Khailas Tile, etc. Before exploiting such geothermal energies, obtaining a proper theoretical and technical mapping of the prospective geothermal plants is required, which is currently immature. Bangladesh is blessed with very large deltas and got a large sedimentary basin. Recently, Anglo MGH, a private company in Bangladesh, has initiated a geothermal plant of 200 MW capacity at Saland of Thakurgaon district. The project is the first-ever with geothermal energy and has been officially approved by the Ministry of Power, Energy and Mineral Resources, Bangladesh. Small stand-alone diesel generator-based power systems or renewables-based power systems often stand promising to disseminate energy to the country's every corner. Small-scale diesel generators and solar PV can engender mini-grid hybrid power systems. Among the renewables, the prospects of Solar Home Systems (SHSs) are one of a kind. The SHSs, however, are of small capacity and can only meet the basic demands of individual households. The SHS was initiated in 2003 and has been adopted worldwide since then. By 2017, around 4.12 million SHSs were deployed across Bangladesh. These SHSs consist of three basic parts: a small lead-acid battery, a solar charge controller, and basic domestic loads (such as lights, fans, etc.) and have been serving more than 16,000 people economically in off-grid rural areas (Samad et al. 2013). The Infrastructure Development Company Limited (IDCOL), Bangladesh, has financed 26 solar mini-grids that provide a cumulative generation capacity of 5 MW and are projected around 300 tons of CO_2 reduction during their service lifetime (IDCOL 2021). Currently, 4 SRPs are in

Table 2 Wind mapping across different locations in Bangladesh (Hossain and Ahmed 2013)

Places	Sensor height (m)	Annual avg. wind speed (m/s)	Organizations
Kuakata	25	4.54	Wind mapping at 7 places by Local Government Engineering Department (LGED)/Bangladesh Centre for Advanced Studies (BCAS)/ Department for International Development (DFID) (1996–1997)
Kutubdia	25	4.18	
Char Fassion	10, 25	3.28, 4.0	
Patenga	25	3.84	
Cox's Bazar	25	3.34	
Noakhali	25	2.96	
Kutubdia	25	4.18	
St. Martin	25	4.69/4.56/4.8	Wind mapping at St. Martin by Bangladesh Council of Scientific and Industrial Research (BCSIR) (1999–2001)
Patenga	50	6.7	Wind mapping at 5 places by Bangladesh Power Development Board (BPDB) (2003–05)
Feni		6.2	
Kuakata		6.89	
Kutubdia		6.73	
Mognamaghat		7.1	
Kuakata	30	4.23	Wind mapping at 10 places by LGED/ Bangladesh University of Engineering and Technology (BUET)/ United Nations Development Programme (UNDP) (2005–07)
Pakshy	30	2.78	
Khagrachari	20	3.28	
Naogaon	20	1.92	
Panchagarh	20	3	
Kishoregonj	30	2.37	
Kutubdia	20	3.58	
CUET	20	2.33	
Munshigonj	40	6.26	
Sitakunda	30	4.15	

operation with a cumulative capacity of 3.07 MWp. IDCOL has targeted to achieve around 300 MWp from SRPs by 2022 (IDCOL 2021).

Moreover, the national grid can be augmented by renewable energy generation across the country: solar energy generation from the southeast parts, wind energy generation from the southern parts, geothermal energy from the northeast part, and SHSs. The grid-connected microgrid can transfer surplus energy generated from one part with lower load demand to the site of large load centres. Moreover, during any fault or maintenance occurrence, the microgrid can be operated in islanded mode, sharing energy near the generation sites. Such microgrids could comply with site-specific activities such as carrying emergency loads in military applications, uninterrupted power supply to the data centres and hospitals, economical energy to the small-scale industries. Shoeb and Shafiullah (2018) proposed renewable-based islanded microgrids to supply rural domestic and irrigation demands. The optimised model was evaluated in terms of performance matrices, such as the cost of electricity (COE), greenhouse gas (GHG) emissions, net present cost (NPC), and renewable energy fraction (RF). The result represents the suitability and feasibility to meet the irrigation demand with renewable generation from solar photovoltaic during the daytime. Masrur et al. (2020) analysed the techno-economic-environmental suitability of an islanded microgrid in Bangladesh's remote island. The authors summarised the feasibility of a PV/Wind/Diesel/Battery hybrid microgrid than the current diesel-based system. The proposed hybrid microgrid can reduce the cost by 28%, constituting 44% of non-renewables and 56% of renewable sources. The model also decreases around 23% carbon emissions. A decentralised microgrid is also a feasible solution to maintain the load demand in Saint Martins islanded of Bangladesh. The individual stand-alone energy systems can be linked in a microgrid by forming a swarm electrification scheme. Ishraque et al. (2021) proposed an optimal sizing and assessment of an islanded microgrid. The microgrid is composed of photovoltaic battery-diesel generators and can economically supply the school's load demands.

In addition to the traditional use of microgrid systems to better utilize distributed generations from renewable sources, the microgrid system could also benefit in implementing Combined Cooling, Heat, and Power (CCHP) systems in Bangladesh. In an interconnected grid system, such as the CCHP, different sources of energy (heating, cooling, natural gases, renewables, etc.) are coupled together, and energy is exchanged among them. The coordination of different energy carriers within the sub-systems of the interconnected system is analysed to ensure better energy production efficiency and saving costs. In this context, an interconnected hub or ring system is proposed (Geidl et al. 2007), where energy can be converted, exchanged, and stored. The hub acts as the interface of multi-carrier systems and generally considers electricity and natural gases as the input and provides diverse services ranging from heating (heat exchangers), cooling (compression chillers), electric vehicle (charging station), and electric power (electric loads) as the outputs (Mancarella 2014). The efficiency of the system ranges from 60 to 80% while reducing the use of carbon and other pollutants from the energy sector. This multi-carrier energy hub system is truly a potential candidate to consider and implementation of a microgrid system can buttress its proper operation. Thus, the development and implementation of a microgrid system implementation can be a major revolution and solution to the recent future's probable power crisis in Bangladesh.

Challenges of renewable energy-based microgrid

When microgrid is facilitated by incorporating distributed renewable generations, which are intermittent, stability controlling becomes more demanding. Moreover, the development of newer infrastructure to attain efficient grid management in terms of power generation-transmission-distribution, communication between the consumers and consumer-market, and control of privacy and data handling impose more technical and financial overloads (Chowdhury et al. 2015). The environment is also essential since microgrid generation is based on renewable generation. Thus, irradiance level, humidity, wind velocity, sunny days, wind flow path, and others should be well documented while the microgrid initiative is considered (Shafiullah et al. 2012). In this part of the investigation, some significant challenges of renewable energy-based microgrid systems are detailed, focusing on current research outlined challenges with smart grid technology in developed and developing nations. The major challenges with renewables-based microgrids can be classified as technological, financial, environmental, and political, and regulatory challenges.

Technological challenges

In the completion of any large-scale technical project, such as the implementation of renewable-based microgrid systems, there appear many technological drawbacks and shortcomings in each step of the progress. The technological

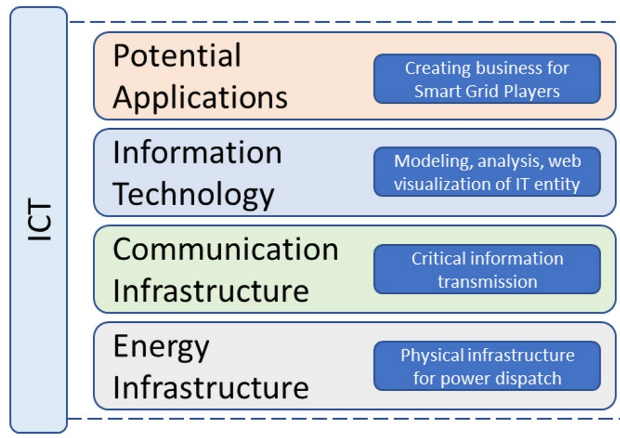


Fig. 5 A microgrid framework integrating energy infrastructure with communication infrastructure, information technology, and potential business applications (Gungor et al. 2013)

challenges for microgrid implementation can be divided into two categories: infrastructure implementation and electrical operation.

Infrastructure Implementation

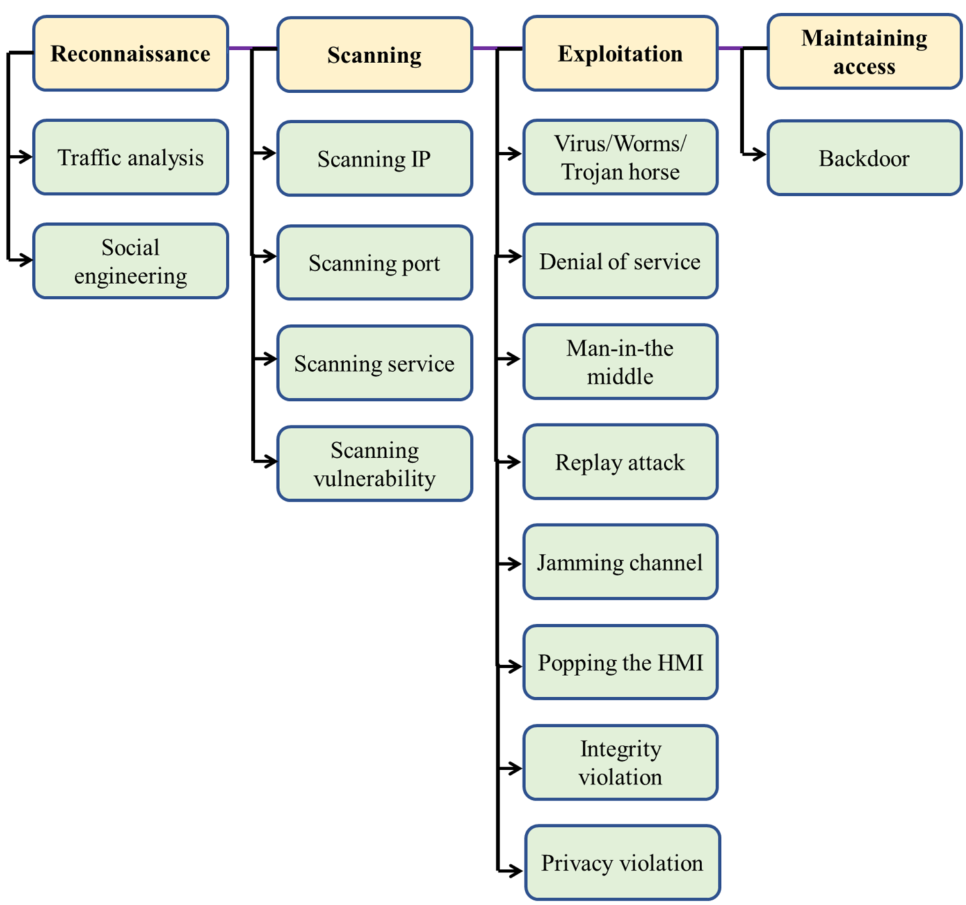
Microgrid operation requires advanced and improved electrical and communication infrastructures. Referring to Fig. 5, a microgrid system's framework is the accumulation of energy infrastructure, communication infrastructure, information technologies, and business applications (Gungor et al. 2013). A conceptual outline of planning, documenting, and organising the distributed generations and integrating them into a resilient grid system is provided by the National Institute of Standards and Technology (NIST) (Greer et al. 2014). NIST has sectorised the smart grid actors and applications into seven sectors which are outlined in Table 3 (Gopstein et al. 2021). The communications between the consumers and utility can be monitored by implementing a smart meter (SM) and advanced metering infrastructure (AMI). IEC (International Electrotechnical Commission) 61,850 standard refers to the required communication networks and systems for power system automation to realise distributed generation. Two-way real-time communication between the end-users meter and the central system can be initiated by using wireless (WiFi, Wi-sun, Zigbee, WiMax, hybrid) or wired connection using power line carriers. A smart meter enumerates the power-sharing between the consumers, consumers' generators to the utility, and vice versa. It exchanges the monitoring data between the central management and the customers in both the grid-tied and islanded operation mode (Arritt and Dugan 2011). Digitization of the communication line is required to handle the large data volume and ensure a fast connection between the actors and applications.

Table 3 Sectorised domains in the conceptual model of the smart grid by NIST (Gopstein et al. 2021)

Domain	Description
Customer	Where electricity is consumed, sub-domains are homes, commercial and industrial customers. Actors may also generate, store and manage energy use
Markets	Where grid assets are exchanged, actors are the operator and participants in electricity markets
Service provider	Where support services for producers, distributors, and customers are performed, actors are organizations providing services to electrical customers and utilities
Operations	Where the proper operation of the power system is ensured, actors are the managers of the movement of electricity
Bulk generation	Where the delivery of electricity to the customer starts. Actors are the generators of electricity in bulk quantities and may also store energy for later
Transmission	Where the bulk transfer of power from generation to distribution is done, actors are the carriers of electricity over long distances and may also store and generate electricity
Distribution	Where transmission, customer, consumption metering, distributed generation, and distributed storage interconnect. Actors are the distributors of electricity to and from customers

Centralised or distributed control management systems can be considered for efficient operation. Smart sensor with the internet of things (IoT) needs to be implemented to accumulate real-time data, monitoring and forecasting the ambient and system parameters. Moreover, to ensure automatic monitoring, control, recovery, and protection of the grid operation and stability, big data analysis has been considered in literature with algorithms of artificial intelligence and neural networks. However, cybersecurity comes along with the digitization process. The cyber attackers follow the same basic steps to compromise the system, and their penetration depth depends on the systems' security level. The cyber-attacks can be classified as Fig. 6, depending on the attacking cycle (Mrabet et al. 2018). Thus, countermeasures need to be ascertained to prevent any malicious cyber-attack such as denial-of-service (DoS), distributed denial-of-service

Fig. 6 Attacking cycle-based cyber-attacks classification for a microgrid system



(DDoS), man-in-the-middle, SQL injection, and malware attacks (Kurt et al. 2019). The erection of the infrastructure for the grid's profound resilience in the horizons of efficient communication between the utility and the microgrid, cyber-physical security, distributed network topology formation, renewables integration, automatic controlling, and real-time monitoring is a major challenge. Bangladesh lacks the maturity of consumer end renewable generation, AMI and EM techs, and advanced cyber-physical control in the current traditional power distribution units (Karim et al. 2019). As such, the microgrid revolution will require tremendous afford from both the consumers and utility companies.

Electrical operation

The microgrid system should demonstrate resiliency in terms of system operation, control, and protection. The Energy Independence and Security Act (EISA) was passed in 2007 to modernise the traditional grid to the smart grid (Us Epa 2013). EISA sets the basic description and parameters for intelligent grid functionalities and efficient management. A modern microgrid's electrical operation must follow EISA in terms of operation, stability, distributed energy resources (DERs) integration, smart equipment, and electric vehicles, and demand-side management.

Operation management Microgrid systems can be operational in both the grid-tied and islanded modes. The transition from the grid-tied mode to the islanded mode of operation leads to severe fluctuations in frequency and system voltages. Moreover, switching or curtailing any significant amount of distributed generations burdens the protective equipment. One of the microgrid system's significant challenges is the unavailability of protective equipment due to variable and often small magnitudes of the system parameters. Hooshyar and Iravani (2017) evaluated the performance of protective equipment such as directional overcurrent, distance, and differential relays are performed during various faults and generation conditions of the microgrid. Thereafter, a few significant controlling challenges and simulations are outlined to demonstrate the 'plug and play' schemes with distributed generation sources.

Stability management Distributed generators (DGs) are the primary power-providing components of the microgrid. Normally, these DGs can be integrated into the microgrid through an interfaced power electronic converter (for photovoltaic (PV), small scale wind and gas turbines, flywheel converters, supercapacitor energy storage, and batteries) or can be connected to microgrid directly (induction generator, diesel generator, and small-scale hydro). In a microgrid with renewable energy sources, inverter interfaced DG imposes a dynamically complex stability issue. Shuai et al. (2016) classified the microgrid stability by considering the operation modes, types of disturbances, time frames, and physical characteristics of the instability. According to Fig. 7, microgrid stability issues can be categorised under grid-tied and isolated operational modes (Shuai et al. 2016). The stability of the grid-tied way of operation is primarily controlled and dependent upon the utility grid. There is a small-signal stability issue for both the modes with the droop-gain optimization technique. However, during large disturbances such as short-circuit faults and outage of large generating units, consideration needs to be taken in terms of dynamic responses of the DGs, power flow characteristics optimization, and con-

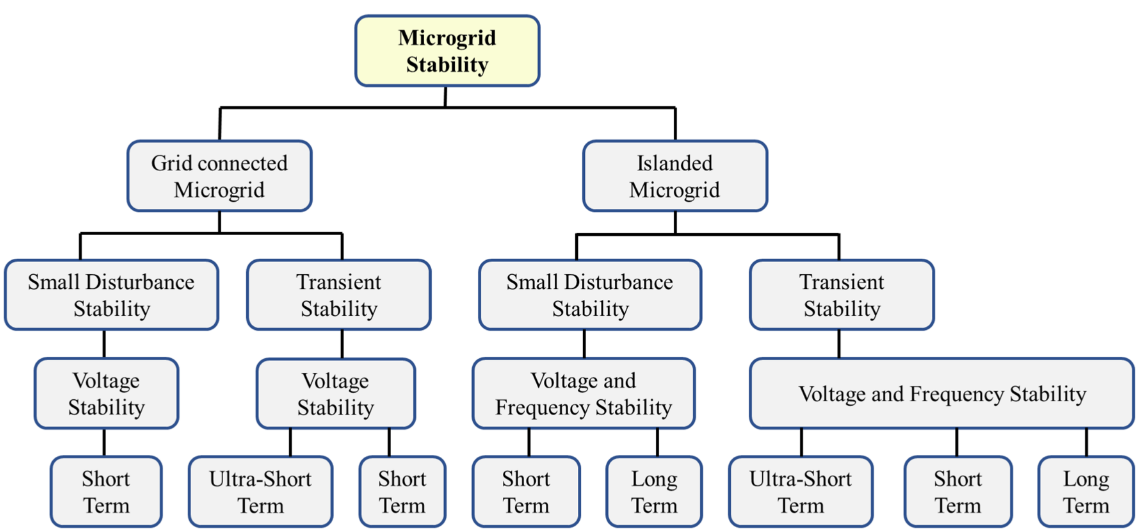


Fig. 7 Representation of different types of microgrid stability based on the time frame and physical characteristics of the instability (Shuai et al. 2016)

trol strategies to control the fault current contribution to the consumer grid (Zhao et al. 2019). In islanded mode, large fluctuations in frequency and voltage can change the stability limit during switching and curtailing DGs in the microgrid (Shoeb et al. 2017). Fault detection can be achieved by v/f controlling the distributed generator sources. A large inrush current can burden the inverter operation during switching. As a result, transient stability within the time frame of ultra-short-term, short term, and long term (for islanded mode only) needs to be appropriately controlled.

Distributed generation management The renewable generation's dependency on the ambient weather conditions results in intermittent, unpredictable, and variant energy production. The power production from these DGs varies abruptly and can cause stability issues. During peak hours, the load demand increases.

To comply with such a dispatchable load, a battery energy storage system is considered to store surpassed energy during the lucrative environmental presets and increase grid stability. However, the increase in power converter stages results in harmonic insertion to the system and congestion in the distribution networks (Gaviano et al. 2012). During the operation's islanded mode, the DGs outputs are shared via SM units among the consumers. A slave controller unit is implemented for controlling the power-sharing and stability management between the end-users.

Smart appliances and electrical vehicle management Smart consumers will participate prominently in future smart grid demand management by adequately scheduling the DERs and controlling DGs' operations. Smart consumers use information and communication technology (ICT) devices to communicate with utility companies to optimise electricity consumption, to decrease electricity cost, and to make sure comfort, availability, and ease of use of electrical energy whenever needed (Sheikh et al. 2019). A rooftop solar panel, plug-in electric vehicles (PEVs), smart metering devices, home appliances are some of the schedulable devices of a smart consumer's household (Alilou et al. 2020). PEVs can pose a risk in energy management if they are plugged into the electrical system during peak hours. However, the discharge of electricity via vehicle-to-grid (V2G) technology can abate the utility's burden during the peak demand. Figure 8 shows a pictorial depiction of battery electric vehicles (BEVs) and energy storage units (ESU) in a grid-tied renewable energy system (Savio et al. 2019). Suman et al. (2020) studied the prospect of electric vehicles (EVs) scenario and have proclaimed that in the next 5–10 years, EVs will be a major automobile stakeholder in Bangladesh. The scheduling and management of smart appliances with high-

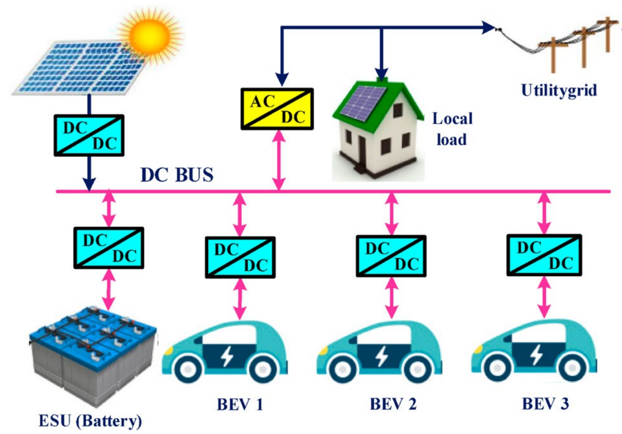


Fig. 8 A pictorial depiction of BEVs with V2G technology in a grid-tied renewable energy system with ESU (Savio et al. 2019)

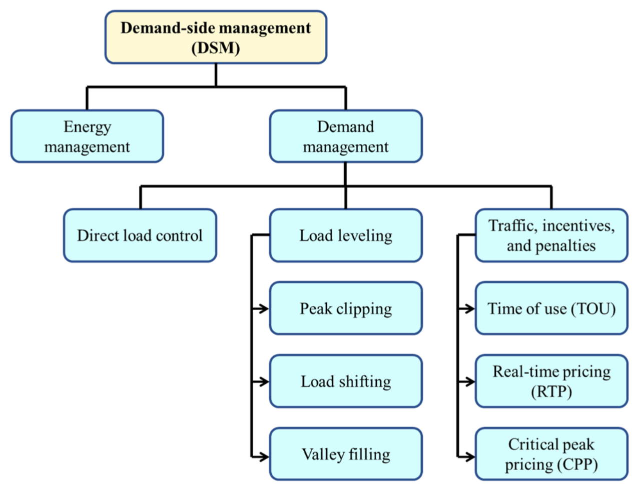


Fig. 9 Demand-side management (DSM) programs

intensity inductive loads, intermittent DERs, and EVs will be a significant challenge to tailor.

Demand-side management Electricity demand fluctuates very abruptly in a short time frame, and to cope with that, power systems have to curtail/add additional/extra power generation units. While efficient running costs ensure throughout this process, the standby generating and storage units incur extra charges and yield system instability (Vincenzo et al. 2011). Demand-side management (DSM) concerns diverse activities related to consumer-end energy management. DSM controls and tailors energy generations, energy efficiency, and energy storage. Moreover, DSM ascertains the demanding device installations, policy formulation, regulation modification, and entity education. DSM programs are categorised in Fig. 9 (Philipo et al. 2020). A two-stage real-time DSM method can dynamically optimize the operating cost and ensure a quality power balance during any ambiguity in the supply or demand side using the historical and real-time information of the response executors (REs). DSM reduces the system congestion and improves stability, and using neural network technique, DSM forecasts the system operation days ahead of any fault (Palma-Behnke et al. 2011). Thus, efficient collaboration between a multi-agent-based microgrid-utility system, improvised, dynamic, and good predictability attributed to the DSM scheme needs to be ensured.

Financial challenges

Microgrid implementation requires a large sum of financial investments even years before the actual operation date due to the lacking of numerous infrastructures and equipment for proper operation via communication and power lines. Setting up DERs, AMIs, EMs, power converter stages, master–slave controlling systems, switchgear, protective devices, and data management needs huge capital costs (Oueid 2019). Table 4 represents the balanced cost of system equipment for installing a 5 MW microgrid. The price increases with the installed capacity of the microgrid. Here, the conventional generation units can contribute 76% and 54% of the campus/institutional and community microgrid's total cost, respectively. The soft costs (engineering, commissioning, regulatory, and construction costs) can contribute 43% of the commercial microgrid and 24% of the utility microgrid costs.

Moreover, the energy storage systems contribute 25% of the commercial and 15% of the community microgrids' total costs. Other costs include the cost of ICT upgrading, advanced metering, primary secondary and tertiary control, and distribution system architecture development. Focusing on the variation of microgrid system implementation cost to the project size (Fig. 4), and then breaking the total costs into equipment costs regarding the capacity of the microgrid (Table 4), it is clear that a tremendous amount of initial financial incentives is required to start and continue the microgrid project.

Environmental challenges

A microgrid system consists of small to medium scale distributed energy resources of both renewable (PV, wind, small scale hydro, geothermal, etc.) and conventional energy sources (small scale diesel, furnace, and others) (Lopes et al. 2013). Solar radiation via heat and light converts to PV energy, the temperature of the earth's surface controls the wind flow, i.e., the wind energy production. Moreover, the photosynthesis process of the plant planets converts solar energy. It stores them, and the energy can be extracted from the fermentation of plant parts (leaves, trunks, woods, etc.) as biomass energy. Also, solar irradiation controls the rain precipitation and humidity, thus controlling hydro energy generation. These renewable generations are thus intermittent. Bangladesh is a low-lying riverine country with a tropical monsoon climate. The temperature during the summer (June-November) ranges from 38 to 41 °C, and during the winter (December-January), it is 16–20 °C. In Bangladesh, the average solar irradiance can range between 215 W/m^2 (north-west) and 235 W/m^2 (south-west) for each day. The country's farm size is below 0.1 hectares, about triple of required to meet the demand from 160 million inhabitants. Moreover, the rooftop solar panel initiation is also tricky due to the highly dense population living within the big cities. The rural households generally stack near the river line and are quite volatile. During climatic hazards such as droughts, cyclones, and earthquakes, most families lose their financial solvency and lose their houses (Metcalfe 2003). The wind plant also suffers from adequate sites for economically feasible wind power production and adds that to the local grid (Uddin et al. 2019). In such versatile weather presets, sufficient planning is a primary challenge to deploy a renewable-based microgrid system.

Regulatory challenges

Lucid policies and legal procedures are required to ensure efficient, fair, and secure supply and demand management of microgrid systems. The development of renewables-based

Table 4 A 5 MW microgrids equipment cost contribution as a ratio

Component	Cost ratio (%)	Description
Distributed energy resources	25–30	Renewable energy resources, energy storage devices, controllable loads
Switchgear and protection equipment	20	Switches, circuit breakers, isolators, bidirectional relays, protective planning, and studies
Communications and controls	15–25	Communication: real-time communication, Wifi/WiMax/5G/other digital communication infrastructures, protocols. Control: centralised/decentralised controlling, power-electronic converter stages, smart metering, primary-secondary-tertiary control
Site engineering and construction	30	System design, testing, and validation
Operations and markets	5–15	Operation and maintenance, market acceptance, business policies, and stakeholder management
Digital security	5–10	Database management, system optimization, remote controlling, cybersecurity

microgrids can mostly be hampered if there are inadequate government policies and market opportunities. Regulatory measures (standards and codes) can reduce extraneous costs and risks during the microgrid operation. Policies ensure a stable investment environment and provide predictable project revenue streams. Lack of mature policies can render unsuitable and highly distinctive grid implementation across the region. The microgrid project requires a large capital investment. Delay in the authorization of private projects and private investors' participation marks a significant barrier for developing countries due to corruption and active political gameplay. One major problem of the renewable-based microgrid system is the initial costs, making it lose the market by the fossil-based power generation since fossils' initial costs are subsidised mainly (Masrur et al. 2020). The inadequate renewable-based business model renders higher energy production costs and makes customers repelled by the renewable generation. Since the customer does not incline towards renewables, the investors do not put their capital on the renewable energy market, and the cycle repeats. Lack of government policy to subsidize renewable generation is not accosted. Policies relating to the government and private sector collaboration on renewable production and grid modernisation are still far behind. Though in areas solar photovoltaic system is sporadically visible, a microgrid system initiation is a big challenge.

Suggestions to overcome the challenges of renewable energy-based microgrid

Rural electricity is mostly used in household lighting and pumping, cattle farms, street lighting, and irrigation purposes. About 15% of the country's gross domestic income (GDP) comes from the irrigation sector. Bangladesh has been enjoying renewable energy sources involving solar plants, solar home systems (SHS), hydro, and Biomass. The grid-connected and islanded microgrid system seems lucrative to share the generated energy across every corner of the country (Bhattacharyya 2015). In a developing country like Bangladesh, implementing the microgrid system will need a longtime initiative and sufficient planning. In this portion of the investigation on microgrid systems from Bangladesh's perspective, some technical and non-technical suggestions are outlined that need to be considered while planning for implementing the microgrid system.

Technical suggestions

The primary problem of implementing a renewable energy-based microgrid system in Bangladesh is the inadequate infrastructure and undeveloped current grid system. Moreover, renewable energy generating system, efficient power electronics converter stages, battery energy storage system, bidirectional advance measuring units, protective devices, proper operation at the PCC, grid resiliency for fault and instability, microgrid management system, communication architecture, data management, and mining.

Renewable energy generation

To enforce convenient solar energy generation, plant environmental variables such as solar irradiance, solar cell inclination, wind, solar cell shading, amount of light intensity, and others play an essential role (Rabaia et al. 2021). A case study in Greece shows that the solar cell performances show a negative linear dependency on the projected solar radiation levels. However, the output increases with an increase in the radiation. With the seasonal variation of solar irradiance, the output from polycrystalline material varies. Si-based solar cells are used in industrial production though Si material renders a solar to electricity generation efficiency of ~ 20%. To improve solar cell efficiency, efficient maximum power point tracking techniques are enjoyed in the literature (Faranda and Leva 2008). Solar rooftop plants such as SHS can be an effective solution due to their moderate initial cost with low energy generation cost. In the case of wind power, strong winds flow across the country from the northeast and south. A wind turbine can easily capture the wind to produce electricity. According to (Hossain and Ahmed 2013), a wind mapping of Bangladesh's different potential areas is represented in Table 2. It is claimed that though the existing low capacity wind turbines result in unsatisfactory results high capacity (MW) wind turbines can output tremendous electrical energy in Bangladesh if is located at the potential sites. According to (Khadem and Hussain 2006), the coast side of Kutubdia can be considered for small capacity wind turbine installation at 30 m height. For effective utilization of renewable sources, wind and solar hybrid generation can be adopted. Nandi and Ghosh (2009) investigated a wind-PV-battery hybrid power system at Sitakunda that stands economically viable to replace the conventional grid system. Starting from 2013, Bangladesh's government is keen to initiate three wind-based power plants providing around 260 MW of power. With the growing demand for power forecasted to be around 40,000 MW by 2030.

Setting up renewable energy plants can help meet Bangladesh's upcoming growing power demand. Due to the geological situation of Bangladesh being flat, the potential sites for hydroelectricity are not abundant. In the common mission for the Scaling-up Renewable Energy Program in Low-Income Countries (SREP), research has been conducted to outline the potential sites for the small-scale hydropower plant. Thus, proper utilization of the potential sites for hydro energy in micro-hydro and small-scale hydro can initiate a local on-grid or islanded microgrid system in Bangladesh.

Having an agriculture-based economy, Biomass stands as another viable option for implementing a renewable energy-based microgrid system in Bangladesh. The agricultural residue and plant residue is, therefore, significantly higher. Industrial waste, municipal waste, plant residue, and animal manure can be considered for biomass energy production. In this regard, efficient waste management plants can magnify gross generation and increase employment opportunities.

Power electronics converter

Reliable power electronics converter (PEC) stages are essential for the flexible interconnection of load and grid with the microgrid generating plant. Some performance measurement stats can be power density level, installation and maintenance cost, reliability, and efficiency. To improve the PEC units' power density and efficiency, semiconductor devices of broad bandgap value need to be considered (Yamamoto et al. 2020). The heat dissipation from the PECs reduces efficiency and longevity significantly. For this reason, a heat sink can be used to improve the reliability of PEC. The reliability standing of PEC can also be found by condition monitoring (Yang et al. 2010), where few power electronics' conventional uses with renewable energy and a microgrid system are presented. Bragard et al. (2010) investigated the efficient PEC system with a 2 kW-PV system and 100 MW of wind farm with a modular battery energy storage system. Power electronics-based flexible alternating current transmission systems (FACTS) devices can also be considered for the efficient microgrid and smart grid. With efficient controller settings, the PEC can mitigate system unbalance. The weighing factors for proper predictive control of power electronics can be enumerated by incorporating artificial neural network systems (Dragičević and Novak 2019).

Battery energy storage

Energy generated from a renewable source is intermittent and varies abruptly from time to time. To store the energy generated, an energy storage system (BESS) can be adopted. BESS is the most essential and efficient way for energy interchange between consumers, between the user and the utility grid. Moreover, BESS can improve the system's stability and enhance system production during peak hours. Figure 10 refers to the various services provided by energy storage devices (Chowdhury 2020). Lithium-Ion Battery (LIB) demonstrates higher energy density and can operate efficiently for a longer time than traditional lead-acid batteries (LABs). Chen et al. (2020) analysed grid-scale lithium ion-based ESSs with frequency regulation, load shifting, renewables integration, and power management services.

Integration of LIBs with the solar home lighting systems in an isolated microgrid is viable from techno-economical consideration. BESS can also be added at the wind farms

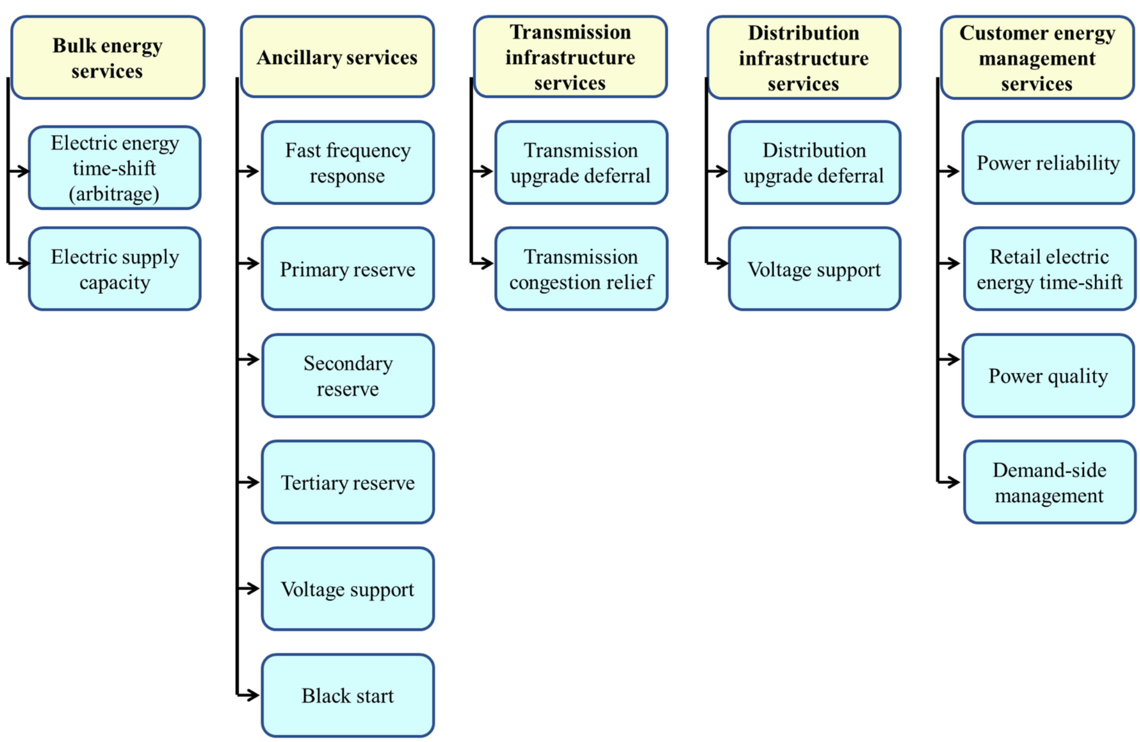


Fig. 10 Big data implementation architecture in Micro Grid system (Chowdhury 2020)

in isolated and grid-tied microgrid operations. Davies et al. (2019) proposed newer battery materials, including traditional lead, lithium-ion, aluminium-ion, lead-acid, sodium-sulphur, flow batteries, and more contemporary wide band-gap semiconductor materials for the future development of BESS that can be feasible for microgrid and smart grid systems. A newer variation of the lead battery can reduce the environmental hazards posed by the LIBs. For proper operation of BESS, efficient controlling and operation prediction is a must. In this context, model predictive control, optimal cooperative control, and droop control could be considered (Morstyn et al. 2018).

Energy measuring units

The development of the current grid system towards the paradigm of a microgrid is a significantly giant step as it refers to upgrade of current power grid lines to cope up with the microgrid system, needs fast and stable power electronic converter stages, energy metering infrastructure, financial incentives to complete the microgrid development, and change in regulatory policies to ensure sustainable and economic electric power to the consumers. A microgrid can be a source to share surpassed energy between the consumers and grids. During the process, energy can either flow inward or outward at the customer end. A smart measuring unit is necessary to measure the amount of energy shared by any consumer-generated from consumers' renewable sources. In commercial AMI with a smart energy management system is investigated and has posited AMI can be used for power quality management and alarming (Palacios-Garcia et al. 2017). A smart measuring-based new energy efficiency controlling system is proposed for partially unresolved schemes with phase-load balancing, load modelling, and voltage control. In smart metering units' applicational benefits and deployment techniques in a microgrid system are investigated (Palacios-García et al. 2015). An appropriate communication system must be provided for fast, efficient and safe operation, and monitoring of smart meters.

Protective devices

Protection is one of the fundamental requirements of an electrical power system. Increased penetration of DERs and their mesh connection to the grid make the protective system of a microgrid very difficult. The intermediate bidirectional fault current differs during the two modes of operation and makes the conventional over-current relays (OCR) mal-operate (Beheshtaein et al. 2019). Two mostly suitable ways to microgrid protection with DERs are voltage-based protection and total harmonic distortion (THD)-based protection. Since the amount of DERs connection to the grid remains variable, an adaptive protection system needs to be considered. The OCR curve optimization technique enhances protection coordination among the relays (Aghdam and Karegar 2017). The optimal settings and optimal curve can be configured by using a hybrid genetic algorithm and linear programming. In conventional OCR and dual settings, directional OCR is used for their performance measurement in a microgrid system (Srinivas and Swarup 2017).

Moreover, a communication-dependent protection scheme is proposed to improve performance matrices. An optimal relay placement system can also be considered to maintain the microgrid's proper operation in both modes using the exchange-market algorithm on the 18-bus microgrid and IEEE 123-bus system (Reimer et al. 2020). Conventionally in microgrid protection, the adaptive technique is used. However, the adaptive approach retains some malfunction shortcomings and the communication system's failure. One possible way to solve the problem is using a hybrid system with a total harmonic distortion method as a back of primary protection failure. Recently, an artificial neural network (ANN)-based fault detection method has been proposed where wide-area monitoring and fault monitoring can easily be deployed without affecting the relays of non-faulty lines (Chaitanya et al. 2020).

Operation at the PCC

The point of common coupling (PCC) is in the interaction point of the microgrid and utility grid. Efficient operation at the PCC can contribute to system stability and grid-tied to islanded modes transition. In a scenario of a multi-microgrids (MMGs) system, the capacity of PCC to maintain current flow among the microgrids and utility grid need to be adequately enumerated. However, the absence of information on the neighbouring microgrids often results in bad congestion at the PCC operation. A bi-level hierarchical structure with a virtual aggregator can reduce congestion in the PCC while ensuring optimum energy management between microgrids and utilities (Khavari et al. 2018).

According to (Litwin et al. 2020), the PCC measurement of different electrical parameters can be omitted by considering an Ethernet communication system with a global positioning system (GPS) pulse-per-second synchronization and droop control parameter shift, this increased reliability. In the proposed technique, synchronisation between the utility end and microgrid end remains even during the islanded mode of operation, benefits fast fault clearance and system monitoring process. This way, the PCC operation, energy management, and synchronization technique should be carried out to provide system reliability.

Microgrid resilience

Every system is bound to a fault, occurring from malfunction or enforced by environmental hazards. Resilience, as of the definition provided by the department of energy (DOE), is the ability of a system or system's components in the milieu of diverse conditions and withstand it. Moreover, the system should be able to fast recover from disruptions to be resilient. In the microgrid system's intrigue operation and management, fault occurrence and resilience to fault should be revised. Environmental scenarios such as lightning, wind speed, and others are also critical. An inverter-interfaced DG model can be considered a controllable voltage source and a virtual impedance for the negative sequence system to select the faulty phase and to improve resilience correctly. The fault occurring in the communication line's sensor or actuator can be compensated by adaptive voltage and frequency control. In an AC microgrid, the technique can help frequency restoration and stable power-sharing. A 3-D droop concept is applied in a hybrid microgrid system to enhance system stability, reduce power oscillations, and proper transient power-sharing during an unbalanced fault (Eisapour-Moarref et al. 2020). The fault response characteristics of different power electronics converter stages are summarised by Meghwani et al., which are essential for settings up the relay (Meghwani et al. 2017). The grid behaviour in high impact, low probability events such as windstorms, hurricanes, cyclones, and others can be observed by quantitative measurement of the grid fragility curves and wind profile (Najafi et al. 2019).

Energy management system

The energy management system (EMS) framework is required to manage and schedule distributed generations and conventional ones and power flow from the microgrid system to meet consumer demands. EMS can be performed by enforcing centralised, decentralised, or distributed control in nature (Harmouch et al. 2018). A central controller in centralised controlling extracts system information, instruction, and data from various local controllers. Only the central controller holds data processing, decision-making, and supervisory privileges. Thus tons' amount of data accumulates at the central computing system, and information from all the nodes or areas of the grid can enforce viable system management. However, due to more DERs and stochastic behaviour penetration, the central controller's control management becomes too complicated and cumbersome. Several local controllers are assigned controlling and protection measures with a defined jurisdiction in a decentralised control system. Each controller analyses local data of less amount in nature, performs the required actuating signal, and makes communication among other local controllers to coordinate. This milieu results in a much simpler system with less cost burden. However, decentralised control can be hierarchically subdivided as primary, secondary, and tertiary control, making the communication, controlling, and stability issues challenging.

MASs gathers complex data from the disseminated DERs and interlink to the organisation. Different algorithms and optimization procedures for efficient deployment of MAS have been proposed involving noncooperative game theory, gossip algorithm, mixed-integer linear programming (MILP), ontology-driven EMS, fuzzy logic system, reinforce learning, machine learning, and centralised-decentralised hybrid EMS. The technique takes into account the stability of operation, including power-sharing between local systems and system constraints from various microgrid system steps. Distributed control scheme renders features of smart microgrid with plug and plays opportunities for the DGs.

Communication architecture

Microgrid management moves towards decentralised-distributed systems that will ensure system reliability, security, and required performance. A fast, flexible, and adaptive communication system must carry out efficient decision-making and protect the distributed systems. The communication system should handle the increasing volume of data traffic or service requests from the increasing number of DERs with real-time monitoring and control capabilities. But RTMS handling demands the knowledge of the tolerable bandwidth and latency associated with each MG application, which generally is unique depending on the kind of system response dealt with. In this regard, IEC 61850 and IEEE 1646 standards should be taken for the specifications related to each requirement. Table 5 shows three primary microgrid applications and required communication systems' bandwidth and latency levels (Marzal et al. 2018). The communication system should maintain quality of service (QoS), providing priority treatment to critical applications and communication packages by ensuring a sufficient bandwidth and latency while nullifying the data loss. Traditionally wired communications were considered to transmit information across the electrical grid due to its reliability, robustness, security, and available bandwidth limits. Ethernet technology is the

Table 5 MG applications and communication systems bandwidth-latency requirements (Marzal et al., 2018)

MG message	Bandwidth (Kbps)	Latency
Demand response	14–100	500 ms-several minutes
Distributed energy resources and storage	9.6–56	20 ms–15 s
Distributed management	9.6–100	100 ms–2 s

only wired technology that can provide real-time operation reliability in a distributed microgrid system. On the other hand, though it comes with a sag in terms of robustness, wireless technologies can ensure cheaper installation, higher security that are highly suitable in a distributed microgrid management system. Depending upon the coverage area, the wireless networks can be categorised as WPAN (wireless personal area network), WLAN (wireless local area network), WMAN (wireless metropolitan area network), and WWAN (wireless wide area network). WPAN topology can be adapted for low power, low area, low complexity, and low transmission rate. IEEE 802.15 and IEEE 802.15.4 standards rule out how to access the internet in wireless network topology (Elkhorchani and Grayaa 2014). Cellular networks such as 4G, LTE (long-term evolution), and HSPA (high-speed packet access) can be considered with mobile ad-hoc networks.

Data management

The large volume of real-time data coming from diverse parts of the microgrid system requires efficient management to enforce required control commands and future predictions. In this regard, techniques such as machine learning, deep learning, and artificial neural network-based approaches would stand promising. Rosato et al. (2019) considered dynamically dispatchable virtual power plants (VPPs with concepts from machine learning and deep learning to predict the distributed generation management in a microgrid. The scheme results in more efficient, reliable, predictable, and dispatchable renewable generations and their contribution to the microgrid. The emergence of internet-of-things (IoT) devices ensures much higher information volume. Microgrids with smart sensors and IoT devices can leverage sensory data. Lei et al. (2020) proposed a prediction method for future electric demand and distributed generations extent of an IoT-driven microgrid utilising a finite-horizon partial observable Markov decision process (POMDP). Big data analysis can efficiently perform tasks involving energy forecasting, smart metre operation, and monitoring, stable and reliable grid operation, segmentation of producer and consumers energy contribution, profitable energy trading, load forecasting with load burden and outage level, and to improve end-user engagement in energy marketing.

Ruiguang et al. (2017) proposed a layered architecture for implementing big data for microgrid operations. According to Fig. 11, after the data collection from the microgrid assets in the data collection layer, they are sent to the data post-processing layer where require data assessment, sorting, outlier detection and correction, and labelling are carried out (Moharm 2019). In the data management layer, the database structure is investigated to sort out structured and unstructured data. The data analytics layer performs the central role by data analysis and data mining; this layer produces data trends, correlation, forecasting, and decision support (Liu et al. 2017). Finally, in the application layer, the results are accumulated. Some prominent tools related to each layer are also attached in Fig. 11.

Cybersecurity

The digitization and increased use of information and communication technology (ICT) systems while implementing the microgrid system can dangerously be inflicted from cyber vulnerabilities.

Complying with the IEEE 2030-2011 standards, the proclaimed smart-microgrid can be classified into three interoperable infrastructures: communication, power system, and information technology, as shown in Fig. 12 (Canaan et al. 2020). The majority of cyber-physical systems (CPSs) attacks start on the communication layers and the central controlling units, where confidential data is stored and analysed for efficient operation and forecasting. According to NIST, the CIA (confidentiality, integrity, and availability)-triad should be maintained to prevent any disclosure, deception, and disruption attack on the grid. Sometimes, a fourth measure, accountability, is considered to address the malicious incidents more constructively. Conventional procedure to detect cyber-attacks involves isolating the compromised area or entity and entertaining passive protective-based cyber resiliency. The adversely tuned cyber-attacks at various boundary entry points can be probed against power systems using a pre-defined statistics-based filtration method (Sun et al. 2018). Another aspect of cyber intrusion detection could be to enumerate communication. However, as

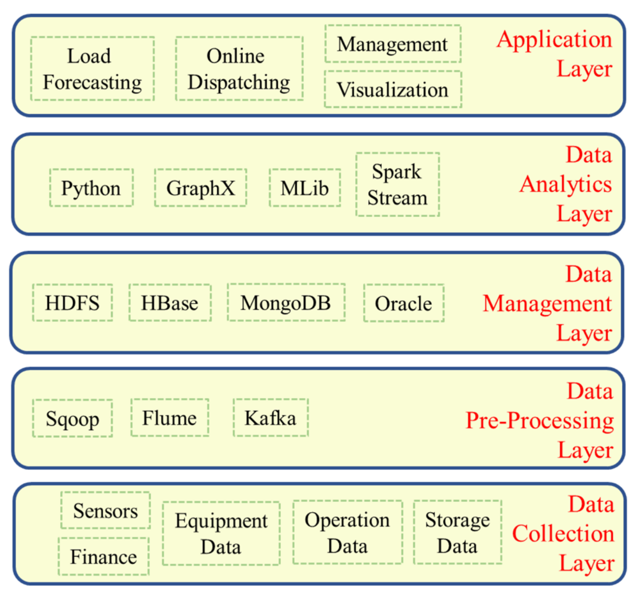


Fig. 11 Big data implementation architecture in Micro Grid system

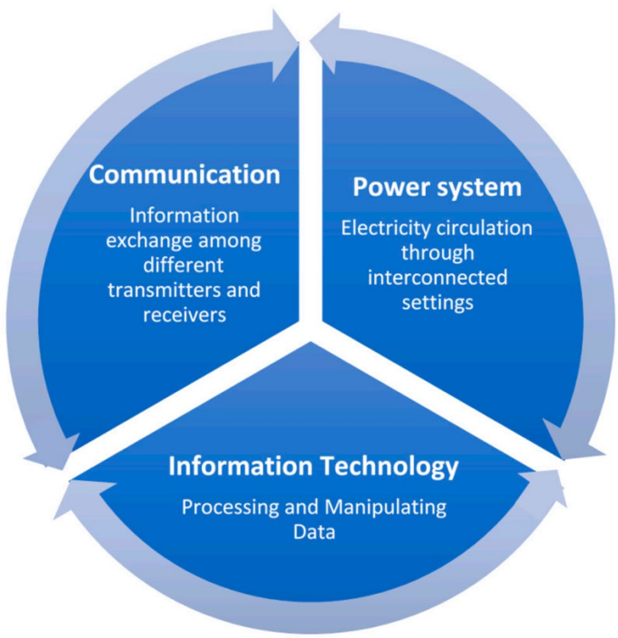


Fig. 12 Smart Grid architecture according to the IEEE 2030–2011 standards (Canaan et al. 2020)

the network expands into single hop-on relay networks, this technique becomes ineffective in large signalling networks. Wang et al. (2016) investigated the potential security vulnerabilities at the transport layer, communication between synchrophasors and phasor data concentrators. Some simultaneous technologies for improving cybersecurity are security Orchestration, automation and response (SOAR), blockchain technology, machine learning (ML), and artificial intelligence (AI).

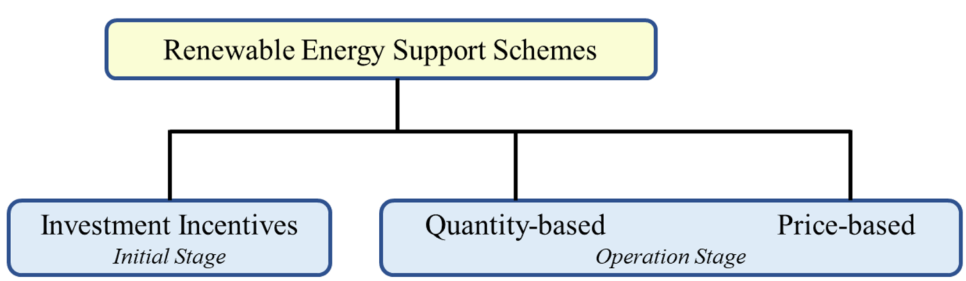
The metric is claimed to be better for affecting decision-making to choose the best mitigation technique for cyber intrusion. The post-intrusion security measure can be dispersed links, local controllers, and master controllers. Each component can detect and isolate corrupted links or controllers fast and economically. The security parameters and process runtime limits can be sent with proper encryption algorithms to ensure profound cyber resistance. Kavousi-Fard et al. (2021) proposed an ML-based cyber-attack detection technique. The method incorporates smart sensors, neural networks (NNs), and proportional-integrators (PIs) of the consumer's EMIs. High accuracy of cyber intrusion detection techniques can be achieved with an algorithm based on symbiotic organism search. Thus, a secure encryption technique optimised as ML-NN-AI models and PIs can be integrated to detect and mitigate cyber-attacks securely. Moreover, as it is found that traditional measures can be taken for preserving data securely at the central database cloud-storage systems.

Financial and policy-related suggestions

From considering the microgrid's technical aspects of establishing a microgrid to its implementation, finance is a necessity. Only a structured policy can back such a tremendous amount of investment and incentives.

Moreover, the government policy should also consider the different stakeholders across different disciplines; removal of barriers to infrastructure, costs, and information while kick-starting renewable generation by private sectors; renewable resources and prospects at diverse geography; and establishment of a stable and commercially sizable energy market (Rommel and Sagebiel 2017). An investment-based and production-based support scheme could be considered to finance system focusing on installation capacity, green energy contribution, amount of feed-in-tariff, and power energy agreement, as is shown in Fig. 13 (Boute 2012). Such a scheme can render financial coverage during the initial and operational stages. The government can initiate carbon taxes to minimise non-renewable fossil-based generation that will encourage more renewable inclination in the long run. The government policy can offset only a small portion of the total cost. For the rest, microgrid relies on different industry-specific financial models. The private equity players experienced with infrastructure, energy, oil, and gas will tend to microgrid investments if the market ensures an above-market return policy with a profitable MG model. Microgrid's major problem is the complex interwoven value system, which makes its computation so tricky and unpredictable. The revenue depends not only on the financial aspects but also on the technical parameters such as stability, resilience, power quality, system management, etc. Quantifying the value of a different technical parameter is required

Fig. 13 Renewable energy support scheme



during implementing any return on investment (ROI) metric. However, focusing on the long-time consumer-end satisfaction of resilient energy facilities and profit from both operational modes of a microgrid could offset such cost burden. Private investors and vendors can play a major role by backing newer tech startups and companies that focus on solving microgrid technological barriers in a much efficient way. Figure 14 shows a commercialization pathway of microgrid with sectorised path-steps and associated investments from the public and private sectors for the USA. It is highlighted that in the USA, the public grant acts as the stimuli to microgrid enthusiasm and project development. Recently in Bangladesh, a government-issued grant for a

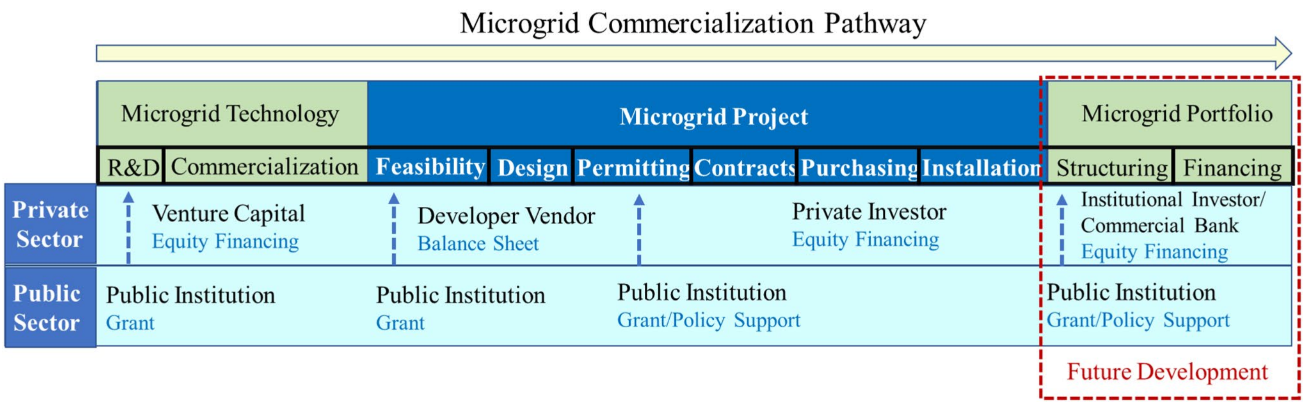


Fig. 14 Financing Sources for Microgrids

Supervisory Control and Data Acquisition (SCADA) system was planned for future control and monitoring structure in a Smart grid system with high intensity and sporadic renewable penetration to the grid (Al-Matin 2017). An indicative outline of the prospective SCADA system is given in Fig. 15 (Al-Matin 2017).

Microgrid's proper operating criterion can be studied under IEEE standard 1547-family, which has specified the technical rules for interconnecting DERs with electric power systems. IEEE standard 1547.4-2011 describes the practice of operation during the active and reactive power control, electric power systems power quality, voltage, frequency regulation criterion, intentional islanding, load power quality, ride-through capability, and policy standards for the isolated and grid-connected microgrid system. IEEE 1547.3-2007 provides a guide for monitoring and communication of DGs. It further describes the rule for interoperability of DGs in interconnected mode. Such regulatory codes should be enforced as mandatory for ensuring a balance operation of the microgrid.

Optimal configuration

In the future, the global clean energy generation from distributed renewable sources is predicted to extend by 8% to reach nearly 8300 TWh. Energy sharing between the DGs can be achieved by constructing the microgrid system with proper sizing and protection level. The optimal configuration of a renewable-based microgrid system considers both the proper generation scheduling and sizing, as well as the required controlling and monitoring of power transfer and load management that ensures cost-effectiveness. For urban university campus-scale load centres, energy demand being perfectly subsidised by solar, wind, and grid backup energy with battery energy storage and converter units, the Levelised Cost of Energy (LCoE) can decrease by 50% when a vertical-axis solar tracker is considered (Shirzadi et al. 2020). Due to intermittency and fluctuation of load demand from season to season, demand management is required for the microgrid. In a hybrid renewable energy system with solar, wind, and BESS, mixed-integer linear programming can be considered for the optimization of real-time pricing model and interruptible model for the demand management and scheduling, focusing on Life Cycle Cost (LCC) and Loss of Energy Probability (LoEP) (Sugimura et al. 2020). The use of hybrid generating units can be extended for supplying a small to medium range of urban residential load centres. A case study in Somaliland, a rapidly economically developing centre, has been reported showing that 58% renewable energy penetration to the current diesel-based grid system can reduce the cost of energy by 30% (Abdilahi et al. 2014). The techno-economic feasibility of considering a hybrid generation comprising of solar, wind, diesel, fuel energy, BESS, and converter stages are further validated by an actual case study in Egypt (Elkadeem et al. 2020). The large-scale renewable-based microgrid system's feasibility is analysed

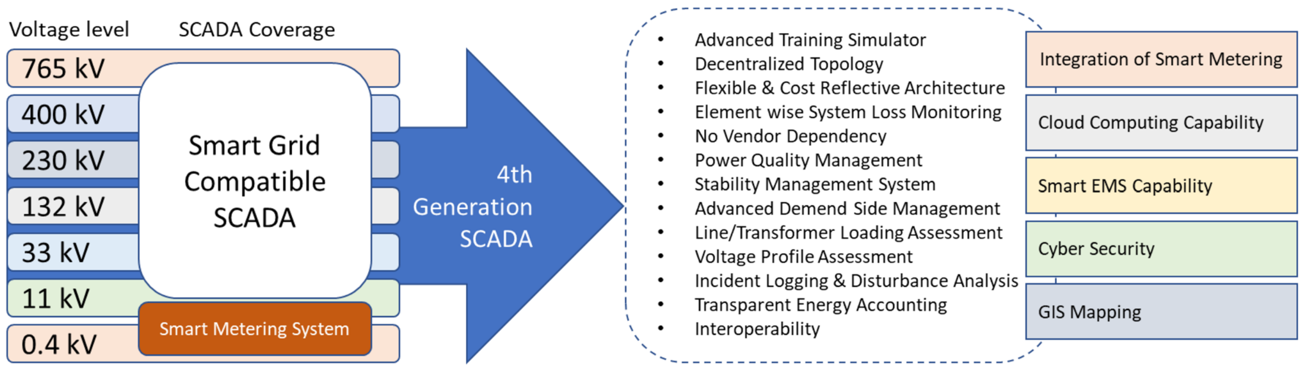


Fig. 15 Future SCADA system of Bangladesh for smart grid implementation (Al-Matin 2017)

by considering the residential community in Beijing, China. It is shown that more than 90% of onsite energy demand could be met by utilising a microgrid system where the total net present cost of microgrid stay less than 57% of the obtained energy (He et al. 2018). In Bangladesh, for clustered load centres, the hybrid solar/wind/diesel/BESS provides the most techno-economic feasibility. In a case study at Saint Martin's Island of Bangladesh, it is shown that hybrid renewable-based microgrids can curtain the system cost as much as 28% along with a 23% reduction of carbon emission (Masrur et al. 2020). Such case studies are often performed using HOMER software which buttresses the assessment of physical, operational, and cost profile mapping. Additional large-scale identification of renewable sources, hybrid systems, scheduling of generating units, and economic benefits in Bangladesh are still lacking. Similar case study, for medium and large scale load centres that have been carried out throughout the developing nations across the globe thus to be properly scrutinised and analysed in Bangladesh situation.

Conclusion

The renewable energy-based microgrid system has been reviewed, including the current renewable generation trend and possibilities in Bangladesh. Then, the aspiration of a renewable-based microgrid system is delineated. The country needs to go through a massive change in updating the current grid structure and enacting intelligent equipment for microgrid commissioning. All the possible major challenges towards penetrating microgrids with the current grid and islanded operation are accumulated one by one. The current research across the globe can explain and give way out to the bulk of the challenges. Some suggestions are particularised in this regard. The paper has been reviewed the most recent research on various challenges and corresponding way-outs during planning, construction, commissioning, and maintenance of a renewable-based microgrid system. The key conclusions from the review of the renewable-based microgrid can be drawn as follows:

- A renewable-based microgrid system is a practicable way to meet growing energy demands and reduce carbon footprints.
- The solar home systems are going to be the consummate player for the microgrid system.
- The hybrid system comprising of small-scale hydro, biomass, and solar photovoltaic is to be considered during the national grid's renewable penetration.
- The key challenges regarding the grid-connected microgrid involve immature national grid, frequency instability, proper controlling of power converter stages, implementation of smart energy infrastructure, deficiency of high-speed communication lines, cost of battery energy storage system, natural vulnerability, the complexity of demand-side management, cybersecurity, lack of protective relays, regulatory challenges, and policy related to microgrid business policy.
- The review has been suggested potential solutions to the challenges regarding microgrids. The technology moves onto adaptive control and stability management by incorporating advanced machine learning and deep learning-based control and stability dispatch. Grid resilience is a necessity while enforcing the latest technologies and equipment.
- The majority of the recent research has used only a test-bed with less renewable generator penetration. It is required to accumulate various numbers of generating plants from both renewable and non-renewable parts.
- Proper policy and complete business plan need to be initiated by encouraging participation from public, private, multi-national, and individual standings for Bangladesh.
- The dynamic stability and resiliency analysis of the current grid during on-grid, islanded, and operation at the

point of common coupling of mini-grid, microgrid and macro-grid are required in Bangladesh.

- The islanded renewable-based microgrid commissioning can be more economical for Bangladesh than on-grid one.

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Declarations

Conflict of interest The authors declare that there is no conflicts of interest of the manuscript.

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