Research Article

Design and Implementation of a Hybrid Solar-Wind-Biomass Renewable Energy System considering Meteorological Conditions with the Power System Performances

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Abstract

This paper presents a performance evaluation of an off-grid PV-wind-biomass hybrid energy system for a remote area named Kuakata in Bangladesh considering dispatch strategy-based control, power system response, and reliability analysis-based stability and feasibility study. The simulation and optimization of operations of the system have been done by the HOMER software using the real-time field data of solar radiation, wind speed, and biomass of that particular area for ensuring economical and environmental feasibility offering the least net present cost (NPC), cost of energy (COE), and CO₂ emission. The result shows that NPC has been reduced by 88 percent, CO₂ emissions have been reduced by 99 percent, the operating cost has been lowered by 99 percent, and COE has been reduced by 92 percent than another available work. Besides, in comparison to traditional power sources, COE has been reduced by 40 percent, NPC has been lowered by 90 percent, and CO₂ emissions have been reduced by 99 percent. The proposed system has also been analyzed utilizing DigsILENT PowerFactory software to find the power system responses, i.e., active, reactive powers, voltage, and frequency responses of the proposed microgrid in a per unit fashion on the occurrence of a three-phase fault. To establish the feasibility of the microgrid, a reliability study considering different reliability indices has also been done. The analyzed hybrid energy system might be applicable to other regions of the world where there are similar climatic conditions.

1. Introduction

Global warming nowadays has become a very critical issue. Production of electrical energy utilizing conventional fossil fuels has also a significant contribution to this global problem. The demand for electricity all over the world is increasing, but this incremental production of electricity by using fossil fuel-based power generation plants causes a higher cost of electricity and higher emission of harmful greenhouse gases (GHGs) which can be mitigated by utilizing distributed microgrid-based renewable power generation techniques like solar, wind, and biogas [1]. To help build a pollution-free better world, utilizing renewable sources of energy has no alternatives. Renewable sources can be successfully implemented for the generation of electrical power [2]. Conventional renewable sources like solar, wind, and hydro are successfully being implemented all over the world to provide a sustainable solution to the energy problem [3]. The main problem regarding renewable source-based power system networks is its uncertain nature. The hybridization of
two or more renewable sources into the system might reduce this problem by offering system reliability and improved efficiency [4].

A tiny version of the conventional electricity grid is called a microgrid [5]. In microgrids, the coverage area of the grid, the amount of generation, and the consumption of electricity are limited [6]. Microgrids have become a part of the “smart grid” concept [7] which allows a two-way flow of information and electrical power [8]. In microgrids, it has been a common fashion to integrate two or more energy sources offering both AC and DC buses [9, 10]. These types of microgrids are referred to as hybrid microgrids [11, 12]. In hybrid microgrids, also known as a hybrid renewable energy system (HRES), there are several types of sources and loads connected. Mostly, the sources include renewable-based sources like solar PV or wind turbines and the load contain various AC/DC fixed or deferrable loads [13]. Biomass energy, on the other hand, is not as famous as solar or wind till today, but it has a great potential to be used as a sustainable solution for electricity. Biomass is
abundant mostly in remote areas from animal husbandry, farming, etc., which can easily be used as a source of energy. Biomass energy is comparatively stable and is more convenient for transportation and storage [14].

Biomass energy can be a potential source of alternative source of energy all over the world. For underdeveloped countries like Bangladesh, the potential is even more. Wastage management has always been a critical issue in Bangladesh. A huge amount of organic and inorganic waste is produced every year in Bangladesh [15]. The organic wastes can be efficiently utilized for the production of biomass-based electrical energy rather than just wasting it or polluting the environment [16]. So, the integration of biomass-based electricity generation in solar PV/wind-based HRES could show a significant impact in solving the scarcity of electricity in the country.

As the development goes on, the electrical load on the grid keeps increasing [17]. Along with residential and industrial loading, nowadays, electrical vehicles and other smart loads are becoming common loads to the grid. To feed all these loads, the grid faces some challenges like stability issues [7] and energy management issues which has a significant impact on the power quality within the microgrid. The dispatch strategy-based control algorithm in this regard might help the grid to mitigate this issue [3].

Research regarding optimum microgrid design has been pretty common in the research arena. The literature in [18] discussed the prospect of developing a solar-wind-based hybrid system to supply power to an underdeveloped region of Sagar island, India, offering the lowest costs and emissions directing to a green solution to electricity problem. The optimal operation planning of a hybrid microgrid for grid-connected and grid-islanded mode has been studied in [19] which serves for rural electrification in Pakistan. In [20], a hybrid PV/wind microgrid system has been proposed for a cement factory in Jordan offering a significant amount of cost and emission reduction. Also, the effect of the integration of li-ion battery within the system has been investigated. An optimized PV/wind/battery system has been proposed in [21] utilizing the energy reliability-constrained (ERC) method which offers greater reliability. In [22], the sizing of a PV/wind hybrid system is studied with a dynamic simulation by utilizing a TRNSYS software-based simulation model. For the optimized hybrid configuration, the cost of integration, environmental and economic results such as payback period, and CO₂ emission mitigation have also been

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**Figure 3:** Flow chart for the complete workflow of the proposed work.
studied in the work. An energy reliability study for a wind-solar-battery-based hybrid system for EV charging station, heat pump operation, and electric office device operation is done in [23]. A similar study has been conducted in [24]. In [25], a new reliability indicator for assessing hybrid microgrids has been proposed, which is based on a probabilistic technique considering the least hourly electric power produced from the solar radiation and wind speed. Also, a comparison with other available reliability indicators is presented along with a suitable case study. An artificial neural network- (ANN-) based forecasting system for sizing and simulating hybrid systems to forecast the system performance for certain locations worldwide has been proposed by the researchers in [26]. ANNs here predict the yearly performance of the proposed hybrid system without doing any kind of dynamic simulation.

For a remote area in Bangladesh, hybrid PV/Wind/diesel generators have been applied for optimum microgrid designing and evaluation in [6]. In this study, the researchers have successfully designed an optimum microgrid but have not considered the impact of dispatch strategy-based control within the microgrid. Reliability analysis as well as estimation of power system response from the microgrid have also been overlooked, which are important to determine the practical implementation ability of the proposed microgrid. An optimal HRES design is done using HOMER, and consequently, the verification of the designed HRES is done using the Simulink model in [27], to solve the electricity problem.

Figure 4: Designed IHMS for 12 months. This figure is reproduced from Shezan et al. [5].

![Diagram](image-url)
in a residential area of Pakistan. The researchers have also successfully implemented the MPC control algorithm in the control of the inverter section of the Simulink model. The researchers did not consider any dispatch strategy-based control but have implemented the MPC controller for stabilization. The research also did not cover the reliability study of the proposed microgrid. A technoeconomic feasibility analysis for a building in France is conducted in [28]. In the work, the analysis carries a sensitivity analysis along with the technoeconomic study. But the study does not consider dispatch strategy-based analysis. The study does not provide any idea about the frequency and voltage or power response of the system either. Also, reliability analysis of the proposed microgrid has not been covered. A similar type

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**Figure 5:** Optimal sizes of each module according to the various dispatch strategies for a proposed islanded hybrid microgrid in the HOMER platform. This figure is reproduced from Shezan et al. [5].

**Figure 6:** Optimal sizes of each module according to the various dispatch strategies for a proposed islanded hybrid microgrid in the DIgSILENT PowerFactory platform. This figure is reproduced from Shezan et al. [5].
of work has been conducted in [29] having similar research gaps. A solar PV/wind/biomass energy system applicable for Kiribati island is designed and assessed in [30] using RETscreen. In [31], Li et al. designed a renewable energy-based energy management strategy for Electric Vehicle (EV) charging stations. In the analysis, dispatch strategy has not been taken into consideration. In [32], Toopshekan et al. have analyzed the performance of a hybrid microgrid consisting of PV/wind/diesel generator/battery considering a new dispatch strategy and the power output responses. In the study, the voltage and frequency responses of the designed microgrid have not been discussed. The prospect of biomass energy has not been studied in the above-mentioned HRESs.

Six different configurations of solar PV, wind turbine, diesel generator, and battery have been investigated by the researchers in [33] for finding the optimal combination for the load demand satisfaction in a remote area in Bangladesh based on minimum energy cost and harmful gas emission. A hybrid generation system is developed in [34] for the Rohingya refugees in Bangladesh. Considering six different combinations of renewable sources, the analysis founds a suitable solution for the area. A sensitivity analysis is also considered in the study, but the study does not consider any dispatch technique-based discussion and reliability study. The voltage, power, or frequency responses from different sources are also missing in the analysis. The analysis also did not consider biomass as an alternative to conventional renewable resources. A similar study considering the Rohingya camp is done by the researchers in [35] having similar research gaps. In [36], a technoeconomic analysis is presented for a stand-alone solar PV-based LED road lighting system in Turkey by optimized designing and sensitivity analysis done in HOMER and DIALux software platforms. The analysis contains no discussion considering various dispatch techniques.

In [37], the researchers have designed and evaluated the performance of a hybrid microgrid consisting of a PV/wind/biomass (biogas) generator considering the cycle charging dispatch strategy. A study on probable grid extension has also been evaluated. A sensitivity analysis has also been presented in the study. However, the study did not evaluate the proposed design considering the power system response of the proposed microgrid. A similar study has been considered in [14] with a similar prospect. This study demonstrated the technoeconomic feasibility of a proposed HRES consisting of

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Table 1: Comparison among different parameters for three cases for four dispatch control.

| HOMER controller       | NPC (million USD) | COE (USD/kWh) | CO2 emersion (kt/yr.) | Operating cost (million USD) |
|------------------------|-------------------|---------------|-----------------------|-------------------------------|
| Load following         | 15.7              | 0.03          | 0.3                   | 0.23                          |
| Cycle charging         | 18                | 0.05          | 0.45                  | 0.4                           |
| Generator order        | 24.9              | 0.07          | 0.93                  | 0.59                          |
| Combined dispatch      | 16.4              | 0.04          | 0.4                   | 0.29                          |

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Figure 7: The difference in various parameters for three cases for four strategies. This figure is reproduced from Shezan et al. [5].
Interrupted energy assessment rate (IEAR)
Average customer curtailment index (ACCI)
Average energy not supplied (AENS)
System average interruption frequency index (SAIFI)
Customer average interruption frequency index (CAIFI)
Average service unavailability index (ASUI)
System average interruption duration index (SAIDI)
Customer average interruption duration index (CAIDI)

**Figure 8:** The reliability index for the designed off-grid microgrid. This figure is reproduced from Shezan et al. [5].

**Figure 9:** Frequency responses for wind turbine modules according to the four dispatch strategies. This figure is reproduced from Shezan et al. [5].
This study offers a significant impact in this research domain by finding an optimal solution for the electricity problem for a test location of West China. Though this study offers a feasible solution, it did not discuss the voltage/frequency responses of the proposed microgrid. In [38], a PV/wind/DG/battery HRES has been proposed and evaluated for the proposed location considering five dispatch strategies and power system response (voltage-frequency responses). The best and worst strategies for the proposed locations have also been determined. However, this study has not considered biomass as a potential source of energy in their analysis. Another research gap for this research work is that the researchers did not study the reliability performance for the proposed microgrid.

Combining the previous discussion, it can be concluded that a HRES combining solar PV/wind turbine/biomass having a dispatch control algorithm on top could perform outstandingly in solving the electricity problem in an isolated area. So, a standalone HRES design to get minimum costing...
(e.g., net present cost (NPC) and energy cost (COE)) and GHG emission for a proposed location in Kuakata, Bangladesh, with power system response and reliability analysis-based evaluation and feasibility test can be a solid contribution in this specific research domain as no other previous works have put their mark in this area. Also, a comparison between the proposed microgrid design and others’ proposed designs is presented in the result section to show the significance of the proposed work. The main goal of this specific research work is to focus on the previously mentioned research gaps of the available literatures considering Kuakata as a test site. The study will be applicable for mainly decentralized operations anywhere in the world having similar meteorological profile and load condition. The rest of the article is organized as Methodology, Results and Discussion, and Conclusion.

2. Methodology

2.1. Data Resource and Location Analysis. The Bangladeshi meteorological department provided daily solar radiation data, average wind speed, and biomass statistics for each month of a certain year required for the simulation of the proposed microgrid in the HOMER platform. The solar insolation on a horizontal surface was calculated using the well-known Angstrom correlation and sunlight hour data from Bangladesh’s southern island area, namely, the Chittagong sea coastal areas. Furthermore, the German Department of Labor and Regulation (DLR) has created a technology that has demonstrated its efficacy for Global Horizontal Insulation (GHI) (a DLR/SUNY model arrangement). The output is evaluated with a spatial resolution of 16.3 km.

Figure 12 depicts the location of Bangladesh’s southern area in the Bay of Bengal called Kuakata (21°49’16”N 90°07’11”E). To calculate GHI, the DLR technique employed satellite data for several parameters such as rainfall, water vapor and vaporiser optical depth, cloud cover, and water vapor. The Bangladeshi Meteorological Department monitored wind speed for a certain year at a height of 30 metres above ground level to compute wind resource data.

Renewable energy analysis with wave energy had not been fruitful yet, because of the insufficiency of electrical power generation. Tidal research stations were set up by the Bangladesh Meteorological Department and Bangladesh Renewable Energy Committee for the practicability analysis of tidal energy [31]. The result was not up to expectation, and that is why just the wind, solar, and average temperature data have been considered for the formulation of the most efficient hybrid renewable energy system. Figure 2 shows the schematic diagram of the proposed hybrid energy system. Figure 3 shows the flow diagram to better illustrate the methodological approach of the proposed research work.

![Diagram showing active power from wind turbine modules according to the four dispatch strategies.](image-url)
installations. A 0.5 percent degradation rate means that the output of a solar panel will drop by 0.5 percent every year. Solar panel deterioration occurs when a solar panel’s power output decreases over time. This term is frequently compared to the product’s lifespan. While solar panel deterioration is undesirable, a high-quality solar panel will have minimal degradation rates that will not have a significant impact on your system’s performance. Solar panels deteriorate over time due to typical wear and tear caused by UV radiation and unfavorable weather conditions. A panel’s performance guarantee includes the rate of deterioration.

P50 type wind turbine has been considered as the output is forecasted to be exceeded 50% over the project’s life. It is critical to obtain on-site wind data for at least one year while planning a wind farm project. Because no one can forecast the wind for the next 20 years, data collected at the meteorological mast during a short period of time is extrapolated to the future using past data. Land-based stations or mesoscale models give this information. Using numerical models, the wind dispersion generated by the long-term corrective process is extended to future wind turbine placements. Finally, the theoretical power curve of the selected turbine type is used to transform the wind resource at each turbine position into production. Gross yield is the end outcome of this entire procedure.

The capital cost of a turbine is the initial purchase price, the replacement cost is the cost of replacing the wind turbine at the end of its life, and the operation and maintenance cost is the annual cost of operating and maintaining the turbine, as shown in the cost table on the wind turbine page (typically 2 percent of the capital cost).

Be cautious to take into account all expenses related to the wind energy system when determining capital and replacement costs, which may include the following:

(i) Rotor and tower of a turbine
(ii) System of control
(iii) Wiring
(iv) Installation

Enter the cost curve for the wind turbine in as much information as you wish in the cost table. You only need to input one row of data in the cost table if each wind turbine costs the same regardless of how many you buy. Enter one as the quantity, as well as the capital, replacement, and O&M expenses per turbine. If you model a system with three wind turbines, the corresponding capital, replacement, and O&M costs will be three times the amounts specified in the cost table.

If the cost of wind energy is not proportionate to the number of wind turbines purchased, use the “Click here to add a new item” link at the bottom of the table to input additional values.

The power curve tab allows you to view the power curve of the selected wind turbine model in both tabular and graphical form. A wind turbine’s power curve shows how
much power it will produce depending on the incoming hub-height wind speed at standard atmospheric conditions. Use this graph to verify that the wind turbine you selected is an appropriate size for your system.

The Turbine Losses tab allows you to derate the turbine performance with several different factors. Enter the numbers and press Enter. The “Overall loss factor” is calculated multiplicatively as in the following equation:

\[ L_{\text{overall}} = \prod_{i=1}^{n} 1 + \frac{L_i}{100}. \] \( \text{(1)} \)

In this equation, each loss percentage is \( L_i \), from \( L_1 \) (availability losses) to \( L_7 \) (other losses). The turbine power output is then scaled down by the resulting factor.

2.2. Formulation of Optimization Problem

2.2.1. Equations Related to Cost Function Minimization and Optimal Sizing. To find the optimal sizes and the number of required generation units, the optimization problems listed in the following (equations (1)–(4)) must be solved [39] to get the optimum sizing of the components as well as to ensure the optimum operation of the designed microgrid. Here, to solve the optimization problem, the HOMER optimizer has been utilized which is a deterministic approach. In the mentioned equations, \( a, b, c, \) and \( d \) refer to the respective different equipment sizes, and \( f_1, f_2, \) and \( f_3 \) express the weights to emphasize the significance of the respective equipment. NPC refers to the net present cost, LCOE refers to the levelized cost of energy and GHG, and \( e_{\text{CO}_2} \) refers to the quantity of greenhouse gas and carbon discharge from the diesel generator, respectively.

\[
\min_{a, b, c, d, f_1 \in N} \left( f_1 (a \cdot \text{LCOE}_{\text{PV}} + b \cdot \text{LCOE}_{\text{WT}} + c \cdot \text{LCOE}_{\text{DG}} + d \cdot \text{LCOE}_{\text{BT}}) \right), \\
\min_{a, b, c, d, f_2 \in N} \left( f_2 (a \cdot \text{NPC}_{\text{PV}} + b \cdot \text{NPC}_{\text{WT}} + c \cdot \text{NPC}_{\text{DG}} + d \cdot \text{NPC}_{\text{BT}}) \right), \\
\min_{e, f_3 \in N} \left( f_3 (e_{\text{CO}_2}) \right), \\
\min_{f_1, f_2, f_3 \in N} \left( f_1 \text{LCOE}_{\text{Total}} + f_2 \text{NPC}_{\text{Total}} + f_3 \text{GHG}_{\text{Total}} \right). \\
\text{(2)} \quad \text{(3)} \quad \text{(4)} \quad \text{(5)}
\]

2.2.2. Equations for LCOE. In HOMER, the LCOE for a HRES may be estimated from [40]:

\[ \text{LCOE} = \frac{C_{\text{annual}}}{L_{\text{primary}} + L_d + E_{\text{gs}}}, \] \( \text{(6)} \)
where $C_{\text{annual}} = \text{total yearly cost}$, $L_{\text{primary}} = \text{amount of primary load}$, $E_{\text{gs}} = \text{annual energy sold to the traditional grid}$, and $L_{d} = \text{amount of deferrable load}$.

### 2.2.3. NPC Estimation

In HOMER, NPC for the proposed HRES may be found from [40]:

$$C_{\text{NPC}} = \frac{C_{\text{annual}} \cdot CRF_{i}}{T_{\text{project}} / C_{0} / C_{1}}$$

where $T_{\text{project}} = \text{lifetime of the project}$, $i = \text{interest rate (per annum)}$, $C_{\text{annual}} = \text{total cost per annum}$, and $\text{CRF}_{i} = \text{capital recovery factor}$.

### 2.2.4. Evaluation of CO₂ Emission

Discharge of CO₂ gas from the HRES is evaluated as follows [40]:

$$e_{\text{CO₂}} = 3.667 \times m_{\text{fuel}} \times \text{FHV} \times \text{CEF}_{\text{fuel}} \times X_{c},$$

where $\text{FHV} = \text{fuel heating value in MJ/L}$, $m_{\text{fuel}} = \text{fuel quantity measured in liter}$, $\text{CEF}_{\text{fuel}} = \text{carbon emersion factor measured in ton carbon/TJ}$, $e_{\text{CO₂}} = \text{emersed CO₂ gas from HRES}$, and $X_{c} = \text{fraction of oxidized carbon}$. 1 g of carbon is included in 3.667 g of CO₂.

### 3. Results and Discussion

The performance of the Kuakata hybrid microgrid system is discussed in this section. After a study to explore the design of an appropriate size microgrid system for Kuakata, the power, voltage, and frequency responses of the Kuakata microgrid are presented using various dispatch mechanisms. Therefore, a detailed comparison is added in this section to evaluate the optimal performance of the microgrid system. The next section delves into the details of the experiment.

#### 3.1. Optimal Sizing

Figure 4 depicts total power generation (electrical) during 12 months based on weather conditions. The presence of sun and wind resources affects energy production from many sources. The location of the data also has an impact on power generation. In the creation of electrical power, the load profile is also a consideration. The battery unit in the LF strategy is the largest, at 10 MW, because the quantity of power supplied by the wind turbine and solar PV module is greater than the load requirement. As a result, the surplus electricity is saved for future use, necessitating larger storage. Among various dispatch systems, for the GO approach, the optimal sizes of each module such as solar PV and converter are the smallest. The cause for this is that under the GO method, the capacity of each piece of equipment is determined by the total load demand and the power generator’s sequence. Following a predefined series of...
generator combinations, GO uses the first generator combination in the list that fulfills the operating capacity.

By using HOMER, the optimal sizes of each piece of equipment utilized in creating the proposed microgrid for four dispatch techniques are presented in Figure 5. The comparison in the graphic shows changes in equipment sizes for the same load. Due to the differences in dispatch strategies, the optimal size of the solar PV, wind turbine, battery, and converter varies.

Based on the DIgSILENT PowerFactory software platform, Figure 6 displays the optimum module sizes for a stable system by using four dispatch mechanisms. With the variation of fuel cost, maintenance, lifetime, and operating cost of components, the NPC can vary. Based on the findings of this study, the NPC for the intended off-grid microgrid has been significantly lower compared to the NPC for existing power plants. The comparison among CO₂, COE, NPC, and emersion for four techniques considering three scenarios has been shown in Table 1 as well as Figure 7. The LF has the lowest CO₂ emersion, NPC, and LCOE at 16.8 M$, 0.4 kt/year, and 0.04 $/kW, respectively. NPC, CO₂ emersion, and LCOE, on the other hand, are the highest for GO, at 0.08 $/kW, 29.5 M$, and 0.76 kt/year, respectively.

3.2. Power System Performance and Reliability Assessment

The reliability index for the planned microgrid is shown in Figure 8 to explain the dependability situation and to compare various dispatch modes. Based on system reliability, the load following (LF) method can be declared to be the best among the others.

The frequency response in case of steady-state condition of the diesel generator module, PV module, and wind turbine module for all four dispatch mechanisms (considering 0 to 2 seconds) is given in Figures 9–12 and is expressed in the p.u. system [5]. A three-phase short circuit defect has been installed in the network to monitor variations in the network’s frequency for 0.1 to 0.3 seconds. As a result, the frequency response diverged and fell from 1 to 0.98 at 0.3 seconds, but it was regained the next second by injecting additional active power.

When the frequency responses from the diesel, wind, and PV generators are compared for the four dispatch mechanisms, it can be seen that the frequency response stabilizes faster with LF dispatch techniques for all modules.

Figures 12–14 illustrate the active powers from the PV, diesel generator, and wind turbine according to four dispatch mechanisms. The active power response for the CC of the diesel generator is substantially different from the other three due to the CC’s operational concept. In the case of CC, the diesel generator is used to charge the BESS, and subsequently, additional generating modules are used to meet the demand. In LF, the wind and solar active power are the highest, suggesting that the system’s maximum power is generated by renewable resources rather than a diesel generator. A three-phase short circuit defect has been injected into the network to perceive the frequency fluctuations in
the network for a range of 0.1 to 0.3 seconds. As a result, the active power response diverged from 1 to nearly 0 between 0.1 and 0.3 seconds. However, it was recovered the next second, just before 0.4 seconds, by injecting an additional active power.

The required energy can be provided by renewable generation, as wind and solar resources are viable and strong enough to create enough electricity to meet the scheduled load demand.

Figures 15–17 illustrate the voltage magnitude response for diesel generators, PV modules, and wind turbines for each of the four dispatch techniques. The BESS module’s voltage response is nearly zero because renewable production provides sufficient active reactive power input to the system that maintains system stability and operational flexibility. According to comparative investigations of all scenarios, dispatch techniques for all three modules such as diesel, wind, and PV generator, the voltage began to decline at 0.15 s due to the introduction of the 3-φ short circuit fault, then began to rise at 0.3 s and stabilized.

Figure 18 shows active power responses, frequency profiles, reactive power responses, and voltage responses for the biogas generator according to the four dispatch strategies. A three-phase short circuit fault has been inserted in the network to measure frequency changes of the network between 0.1 and 0.3 seconds. Therefore, between 0.1 and 0.3 seconds, the voltage response drifted from 1 to nearly 0, but it was improved the next second, just before 0.4 seconds, by injecting additional active power. The system frequency has been set to 1 p.u., and numerous dispatch mechanisms have been compared. The overall system frequency has been kept within the range based on load variances. Our main goal for this research is to present a comparative analysis of different dispatch mechanisms for individual generators like PV, diesel, and wind. We develop a system to monitor the frequency changes in the network from 0.1 to 0.3 seconds due to a three-phase short circuit fault in the network. Thus, the frequency response diverged and decreased from 1 to 0.98 in 0.3 seconds, but it was quickly recovered by injecting extra active power the next second. When a three-phase short circuit occurs in the network, it is vital to keep track of the bus-to-bus frequency between loads and generators in order to keep the system frequency within acceptable limits. The active power responses of all generators based on the four dispatch techniques reveal that the CC and LF strategies ameliorate voltage changes in a shorter time than the other two. Because the generator order is chosen by the availability and biggest renewable resource from a list of possibilities, the three-phase short circuit problem had a substantial impact on GO and CD and CD, selecting a mixture of CC and GO while the GO step is repeated most of the time.

3.3. System Comparison. Tables 2 and 3 summarize the comparison between the proposed islanded microgrid and the work of other researchers. The tables show the differences between the designed off-grid microgrid and other HRES, showing that NPC has been reduced by 88 percent, CO₂

![Figure 17: Voltage magnitudes from PV module for four dispatch strategies. This figure is reproduced from Shezan et al. [5].](image-url)
emissions have been reduced by 99 percent, the operating cost has been lowered by 92 percent, and COE has been reduced by 92 percent. Besides, in comparison to traditional power sources, COE has been reduced by 40 percent, NPC has been lowered by 90 percent, and CO2 emissions have been reduced by 99 percent. All these statistics conclude the importance of the proposed islanded microgrid with system reliability and stability.

As the table describes, the proposed hybrid system offers a huge saving in harmful gas emission. The huge amount of saving has been possible due to the implementation of dispatch strategy-based control. The saving in carbon emission shows the feasibility and impact of the proposed microgrid towards the environment.

4. Conclusion

In this work, an off-grid hybrid microgrid consisting of solar PV, diesel generator, wind turbine, and battery storage devices has been constructed considering dispatch strategy-based control for dependable operation and optimal resource use for a proposed location in Kuakata, Bangladesh. The optimal combination for the proposed microgrid for minimal cost and emissions has been determined, and the performance has been evaluated on basis of power system responses in a three-phase fault and reliability study. Among several dispatch methods, for the proposed location, load following (LF) strategy performs as the best dispatch strategy with the lowest CO2 emissions, LCOE, and NPC and the combined dispatch (CD) approach performs as the worst dispatch strategy with the highest CO2 emissions, LCOE, and NPC. The LF dispatch approach has the lowest CO2 emissions (0.3 kt/year), LCOE (0.03 $/kW), and NPC (15.7 M$). On the other hand, the GO dispatch approach
has the highest CO₂ emissions (0.93 kt/year), LCOE (0.07 $/kW), and NPC (24.9 M$). LF also performed the best in terms of system stability and reliability having stable voltage, frequency, and active and reactive power responses. To ensure a continuous power supply for a remote location like Kuakata, the proposed hybrid system covers three critical criteria: system stability, system dependability, and techno-economic feasibility. Thus, the proposed hybrid off-grid energy optimization model is ideal for remote places and islands having similar load demand and meteorological profile. This study covers the islanded or off-grid mode of the proposed microgrid leaving the grid-connected mode as a future research scope.

Data Availability
Data will be available on request.

Additional Points

Highlights. (i) The design of a solar-wind-biomass-based hybrid microgrid for a remote location in Kuakata, Bangladesh, has been evaluated. (ii) Microgrid design has been optimized for least costs and harmful gas emission. (iii) Dispatch strategy-based control, power system response, i.e., voltage, frequency, and active/reactive power on the occurrence of a three-phase fault, and reliability study were conducted to prove the novelty and feasibility of the proposed work. (iv) Comparison with other works has been presented to demonstrate the significance of the proposed design.

Conflicts of Interest
All the authors declare that they do not have any conflict of interest regarding this research.

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References

[1] Y. Ma, Y. Chen, X. Chen, F. Deng, and X. Song, “Optimal dispatch of hybrid energy islanded microgrid considering V2G under TOU tariffs,” in EES Web of Conferences, vol. 107, article 02007, EDP Sciences, 2019.

[2] M. Fatin Ishraque, S. A. Shezan, M. M. Ali, and M. M. Rashid, “Optimization of load dispatch strategies for an islanded microgrid connected with renewable energy sources,” Applied Energy, vol. 292, article 116879, 2021.

[3] M. F. Ishraque, S. A. Shezan, M. S. Rana et al., “Optimal sizing and assessment of a renewable rich standalone hybrid microgrid considering conventional dispatch methodologies,” Sustainability, vol. 13, no. 22, 2021.

[4] M. Petrolloe and D. Cocco, “Techno-economic assessment of hybrid CSP-biogas power plants,” Renewable Energy, vol. 155, pp. 420–431, 2020.

[5] S. A. Shezan, M. F. Ishraque, S. M. Muyeen et al., “Effective dispatch strategies assortment according to the effect of the operation for an islanded hybrid microgrid,” Energy Conversion and Management, vol. 100192, 2022.

[6] M. F. Ishraque, S. A. Shezan, J. N. Nur, and M. S. Islam, “Optimal sizing and assessment of an islanded photovoltaic-battery-diesel generator microgrid applicable to a remote school of Bangladesh,” Engineering Reports, vol. 3, no. 1, article e12281, 2021.

[7] R. Shi, C. Sun, Z. Zhou, L. Zhang, and Z. Liang, “A robust economic dispatch of residential microgrid with wind power and electric vehicle integration,” in 2016 Chinese Control and Decision Conference (CCDC), pp. 3672–3676, Yinchuan, China, May 2016.

[8] X. Fang, S. Misra, G. Xue, and D. Yang, “Smart grid — the new and improved power grid: a survey,” IEEE Communications Surveys & Tutorials, vol. 14, no. 4, pp. 944–980, 2012.

[9] S. A. Shezan, “Optimization and assessment of an off-grid photovoltaic–diesel–battery hybrid sustainable energy system for remote residential applications,” Environmental Progress & Sustainable Energy, vol. 38, no. 6, article e13340, 2019.

[10] S. A. Shezan and M. F. Ishraque, “Assessment of a micro-grid hybrid wind-diesel-battery alternative energy system applicable for offshore islands,” in 2019 5th International Conference on Advances in Electrical Engineering (ICAEE), pp. 457–462, Dhaka, Bangladesh, September 2019.

[11] P. C. Loh, D. Li, Y. K. Chai, and F. Blaabjerg, “Autonomous operation of hybrid microgrid with AC and DC subgrids,” IEEE Transactions on Power Electronics, vol. 28, no. 5, pp. 2214–2223, 2012.

[12] S. A. Shezan, M. F. Ishraque, L. C. Paul et al., “Assortment of dispatch strategies with the optimization of an islanded hybrid microgrid,” MIST International Journal of Science and Technology, vol. 10, pp. 15–24, 2022.

[13] M. M. Rana, A. Rahman, M. Uddin et al., “A comparative analysis of peak load shaving strategies for isolated microgrid using actual data,” Energies, vol. 15, no. 1, article e15010330, p. 330, 2022.

[14] J. Li, P. Liu, and Z. Li, “Optimal design and techno-economic analysis of a solar-wind-biomass off-grid hybrid power system for remote rural electrification: a case study of west China,” Energy, vol. 208, p. 118387, 2020.

[15] I. Khan, “Waste to biogas through anaerobic digestion: hydrogen production potential in the developing world - a case of Bangladesh,” International Journal of Hydrogen Energy, vol. 45, no. 32, pp. 15951–15962, 2020.

[16] H. Abd El-Sattar, H. M. Sultan, S. Kamel, T. Khurshaid, and C. Rahmann, “Optimal design of stand-alone hybrid PV/ wind/biomass/battery energy storage system in Abu-Monqar, Egypt,” Journal of Energy Storage, vol. 44, p. 103336, 2021.

[17] M. F. Ishraque and M. M. Ali, “Optimized design of a hybrid microgrid using renewable resources considering different dispatch strategies,” in 2021 International Conference on Automation, Control and Mechatronics for Industry 4.0 (ACMI), pp. 1–6, Rajshahi, Bangladesh, July 2021.

[18] A. Goswami, P. Sadhu, and P. K. Sadhu, “Development of a grid connected solar-wind hybrid system with reduction in levelized tariff for a remote island in India,” Journal of Solar Energy Engineering, vol. 142, no. 4, article 044501, 2020.
[19] Z. Ullah, M. R. Elkadem, K. M. Kotb, I. B. M. Taha, and S. Wang, “Multi-criteria decision-making model for optimal planning of on/off grid hybrid solar, wind, hydro, biomass clean electricity supply,” Renewable Energy, vol. 179, pp. 885–910, 2021.

[20] L. Al-Ghussain, H. Ahmed, and F. Haneef, “Optimization of hybrid PV-wind system: case study Al-Tafiah cement factory, Jordan,” Sustainable Energy Technologies and Assessments, vol. 30, pp. 24–36, 2018.

[21] D. Mazzeo, G. Oliveti, C. Baglivo, and P. M. Congedo, “Energy reliability-constrained method for the multi-objective optimization of a photovoltaic-wind hybrid system with battery storage,” Energy, vol. 156, pp. 688–708, 2018.

[22] K. Anoune, A. Laknizi, M. Bouya, A. Astito, and A. Ben Abdelrah, “Sizing a PV-wind based hybrid system using deterministic approach,” Energy Conversion and Management, vol. 169, pp. 137–148, 2018.

[23] D. Mazzeo, N. Matera, and G. Oliveti, “Interaction between a wind-PV-battery-heat pump trigeneration system and office building electric energy demand including vehicle charging,” in 2018 IEEE International Conference on Environment and Electrical Engineering and 2018 IEEE Industrial and Commercial Power Systems Europe (EEEIC / I&ECPS Europe), Palermo, Italy, June 2018.

[24] D. Mazzeo, “Solar and wind assisted heat pump to meet the building air conditioning and electric energy demand in the presence of an electric vehicle charging station and battery storage,” Journal of Cleaner Production, vol. 213, pp. 1228–1250, 2019.

[25] L. G. Acuña, R. V. Padilla, and A. S. Mercado, “Measuring reliability of hybrid photovoltaic-wind energy systems: a new indicator,” Renewable Energy, vol. 106, pp. 68–77, 2017.

[26] D. Mazzeo, M. S. Herdem, N. Matera et al., “Artificial intelligence application for the performance prediction of a clean energy community,” Energy, vol. 232, article 120999, 2021.

[27] E. A. Al-Ammar, H. U. Habil, K. M. Kotb et al., “Residential community load management based on optimal design of standalone HRES with model predictive control,” IEEE Access, vol. 8, pp. 12542–12572, 2020.

[28] M. S. Islam, “A techno-economic feasibility analysis of hybrid renewable energy supply options for a grid-connected large office building in southeastern part of France,” Sustainable Cities and Society, vol. 38, pp. 492–508, 2018.

[29] L. Tribioli and R. Cozzolino, “Techno-economic analysis of a stand-alone microgrid for a commercial building in eight different climate zones,” Energy Conversion and Management, vol. 179, pp. 58–71, 2019.

[30] M. D. Hossen and S. A. Shezan, “Optimization and assessment of a hybrid solar-wind-biomass renewable energy system for Kiribati island,” International Journal of Engineering Trends and Technology, vol. 6, no. 10, pp. 1–8, 2019.

[31] D. Li, A. Zouma, J.-T. Liao, and H.-T. Yang, “An energy management strategy with renewable energy and energy storage system for a large electric vehicle charging station,” eTransportation, vol. 6, p. 100076, 2020.

[32] A. Toopshekan, H. Yousefi, and F. R. Astaraee, “Technical, economic, and performance analysis of a hybrid energy system using a novel dispatch strategy,” Energy, vol. 213, article 118850, 2020.

[33] S. Mandal, B. K. Das, and N. Hoque, “Optimum sizing of a stand-alone hybrid energy system for rural electrification in Bangladesh,” Journal of Cleaner Production, vol. 200, pp. 12–27, 2018.

[34] T. Chowdhury, H. Chowdhury, M. I. Miskat et al., “Developing and evaluating a stand-alone hybrid energy system for Rohingya refugee community in Bangladesh,” Energy, vol. 191, article 116568, 2020.

[35] M. F. Ishraque, M. S. Hussain, M. S. Rana, M. H. K. Roni, and S. A. Shezan, “Design and assessment of a standalone hybrid mode microgrid for the Rohingya refugees using load following dispatch strategy,” in 2021 6th International Conference on Development in Renewable Energy Technology (ICDRET), Dhaka, Bangladesh, December 2021.

[36] A. C. Duman and Ö. Güler, “Techno-economic analysis of off-grid photovoltaic LED road lighting systems: a case study for northern, central and southern regions of Turkey,” Building and Environment, vol. 156, pp. 89–98, 2019.

[37] J. Li, P. Liu, and Z. Li, “Optimal design and techno-economic analysis of a hybrid renewable energy system for off-grid power supply and hydrogen production: a case study of west China,” Chemical Engineering Research and Design, vol. 177, pp. 604–614, 2021.

[38] M. F. Ishraque, S. A. Shezan, M. M. Rashid et al., “Techno-economic and power system optimization of a renewable rich islanded microgrid considering different dispatch strategies,” IEEE Access, vol. 9, pp. 77325–77340, 2021.

[39] S. S. Arefin, “Optimization Techniques of Islanded Hybrid Microgrid System,” in Renewable Energy-Resources, Challenges and Applications, IntechOpen, 2020.

[40] S. A. Shezan, S. Julai, M. A. Kibria et al., “Performance analysis of an off-grid wind-PV (photovoltaic)-diesel-battery hybrid energy system feasible for remote areas,” Journal of Cleaner Production, vol. 125, pp. 121–132, 2016.