Design and Cost Analysis of a Decentralized Hybrid Renewable Energy System-based Microgrid for Insular Rural Area: Hatiya of Bangladesh as an off-grid solution

Nayeem Ahmed
Control and Applications Research Centre
BRAC University
Dhaka, Bangladesh
nayeem.ahmed@g.bracu.ac.bd

Quazi Rian Hasnaine
Dept. of Electrical and Electronic Engineering
BRAC University
Dhaka, Bangladesh
quazi.rian.hasnaine@g.bracu.ac.bd

Shakil Mahmud
Dept. of Electrical and Electronic Engineering
BRAC University
Dhaka, Bangladesh
fabeshakil@gmail.com

Mohammed Imran Thushar
Dept. of Electrical and Electronic Engineering
BRAC University
Dhaka, Bangladesh
thushar.imran@bracu.ac.bd

2023 International Conference on Control, Communication and Computing (ICCC) | 979-8-3503-3412-8/23/$31.00 ©2023 IEEE | DOI: 10.1109/ICCC57789.2023.10165548

Abstract*— A large number of people in Bangladesh, especially in the coastal areas, are still deprived of on-grid electricity power, especially in the country's coastal islands and hilly regions. Getting the motivation to bring them under the blessings of electric power, a design consisting of multiple renewable energy sources is proposed in this paper. Geographically, the country is located in a suitable position for exploiting renewable energy since it locates near the tropical region. This paper presents the design of a hybrid topology-based renewable energy system consisting of solar and wind power and battery support. The design is mainly proposed for the insular coastal region people. Since solar and wind powers have fluctuating natures, feedback circuit-based Multi-Input-Single-Output Single Ended Primary Inductor Converter (SEPIC) is used. The DC-DC SEPIC converter is utilized in boost mode operation. Also, batteries are connected to the system for backup as storage devices in case of gloomy weather. The topology is validated in MATLAB/Simulink environment. Moreover, the design is fed into Homer Optimization Tool with a view to justifying the technical feasibility and economic analysis. Different intermittence situations, solar irradiance, and seasonal fluctuation were also taken into consideration throughout the software assessment. The reason behind using wind and solar energy for hybridization is the lack of infrastructure to utilize hydro power and geothermal energy everywhere in Bangladesh. Although numerous earlier research works analyzed hybrid systems, this work presents a thorough techno-economic analysis of hybrid systems with backup and comprehensive simulation findings. Hatiya, a largely rural island detached from mainland Bangladesh is considered here for analysis. A small community of Hatiya is considered during the simulation in HOMER. All of the analysis is done based on the geographical position of Hatiya in this paper.

Keywords*— *Hybrid Energy, Renewable Sources, MATLAB/Simulink, Homer, Decentralized Hybrid System, SEPIC Converter, Cost Analysis.

I. INTRODUCTION

One of the hardest issues many impoverished and developing countries confront is the absence of power in remote and rural areas. Energy demand is rising due to increasing population and technological development around the world, and statistics show that in 2021, global energy consumption was approximately 14221 million tons of oil equivalent (Mtoe) [1]. A maximum of those energies were produced using hydro-carbon fuels which is a major contributor to CO2 emission. Electricity generation through renewable energy sources like photovoltaic (PV) panels and wind turbines is getting more and more popular worldwide due to global warming, rising energy demand, and price hikes of fossil fuels. As a developing nation, the demand for energy is rising dramatically as a result of the population increase and the emerging industrial revolution in Bangladesh. The main issue the nation is facing at the moment is providing enough electricity to meet demand. In 2021, the total energy consumption in Bangladesh recorded was 46 Mtoe [1]. As of 2020, the country has proven a reserve of 12.53 Tcf of gas and 5.18 MT of coals, which is very little compared to the demand [2]. Though the country has a total installed capacity of 25,284 MW in 2022, a maximum of the plants sit idle due to technical issues and a shortage of fuel to run the plants. The country has to produce 92.67% of the energy from non-renewable sources as of 2022 [3]. Most of the energy was produced from imported fossil which created immense pressure on the economy due to large import bills since Bangladesh has a very little reserve of fuels to produce electricity. These create obstacles to ensuring energy security for the rural people of the country as the demand is rising every year. In these circumstances, attention toward renewable sources alternatives to produce powers to contribute to the country's energy system needs to get momentum. Moreover, a decentralized microgrid system can reduce system loss and transmission costs which

979-8-3503-3412-8/23/$31.00 ©2023

can also bring a large number of people living in isolated rural areas under electrification. Presently, the most advanced renewable energy technologies are those that use wind and solar energy. Due to its geographical position, it is most feasible for Bangladesh to implement projects based on solar and wind power [4, 5]. In this regard, the hybrid system, which consists of connecting small, modular generation (wind turbines, PV arrays) and storage devices, has shown to be the most effective way to meet the energy demand with high reliability, flexibility, and cost-effectiveness. In recent years, numerous projects and technologies have been presented globally to build a decentralized hybrid microgrid system. Ismail et al., in their paper, demonstrated a technical analysis based on the hybridization of PV modules and batteries with micro-turbine. Feasibility of using micro-turbine as a backup source for the rural community of Palestine is presented [6]. Another project is by Mahmud et al., where a hybrid system is made by incorporating solar panels and a bi-cycle paddle dynamo. They used a modified SEPIC converter with boost mode for the loads. The system is built for the insular rural communities of Bangladesh, where there are no on-grid facilities [7]. Imran, in his paper, described an atmospheric water generator for coastal areas of Bangladesh powered by solar panels with contribution from piezo materials. A MATLAB simulation and economic analysis are presented in the paper [8]. Li, in his journal, showed a performance analysis of a hybrid wind/diesel/battery power system. With the help of Homer pro software, analytical results were presented for a small residential area encompassing 280 homes in China [9]. Khan and Iqbal, in their research, exhibited the practicability study of a hybrid system with hydrogen-based storage for applications in Newfoundland, Canada. They also used Homer software as an optimizing and sizing tool [10]. Ma et al. in their paper presented a thorough study and hourly simulation for finding an optimal solution to power up inhabited islands of Hong Kong that are beyond the reach of the utility grid. Their study indicated that the hybrid system of solar, wind, diesel, and batteries could provide optimal techno-economic performance [11]. Investigation into the techno-economic analysis of standalone PV/wind hybrid power systems for remote households in North Eastern India is presented in Bhakta's paper. In this paper, the hybrid system's sizing, optimization, and economic analysis are all carried out using HOMER simulation software [12]. Proper optimization of hybrid renewable energy systems is a key factor in building an efficient system. A methodology is developed in Fulzele's paper for optimum planning of hybrid Solar-Wind systems with some battery backup. HOMER is used to evaluate the integrated system's economic and technical viability [13]. This paper's objective is to design a sustainable solution for isolated off-grid rural areas of Bangladesh. A hybrid system based on multiple renewable energy sources can be a viable solution for a developing nation like this. Combining PV modules with other renewable energy sources makes more sense when looking at the financial advantages (generating electrical power using wind turbines in this project). Furthermore, a detailed mathematical model and simulation are presented in this paper. Considering the contingent nature of these renewable sources, a battery is placed within the system as a backup. To reduce the hardware required in this system, a custom-designed multi-input DC-DC SEPIC converter is used. Then, HOMER solves the optimization problem to better regulate and control the energy flow and maintain a consistent supply of demand. Cost analysis of the system for rural areas is also presented elaborately.

II. Overview and Working Principle of the Proposed System

This proposed system has to be built in such a way that its efficiency is better suitable for the condition of Bangladeshi rural areas. A hybrid renewable energy system typically consists of storage units and more than one renewable module operating in simultaneously. The coastal region's wind and solar energy resources in Bangladesh are taken into account in this study. The system consists of PV panels and wind turbines connected to a custom-designed multi-input SEPIC converter. A closed loop feedback control unit is connected with the wind turbines for a constant voltage output from that. An MPPT charge controller is connected between the solar panels and the converter. The Double Pole Double Throw (DPDT) switch will be used to operate a backup system (batteries) as well. In this arrangement, loads are typically powered by solar and wind resources, and batteries will be charged simultaneously. During the time when there will be no power input from the sources due to weather conditions, batteries will be discharged to meet the demand. The dispatchable components are triggered by DPDT when the output of the source cannot satisfy the load demand. Fig. 1 depicts the simplified schematic diagram of the proposed topology.

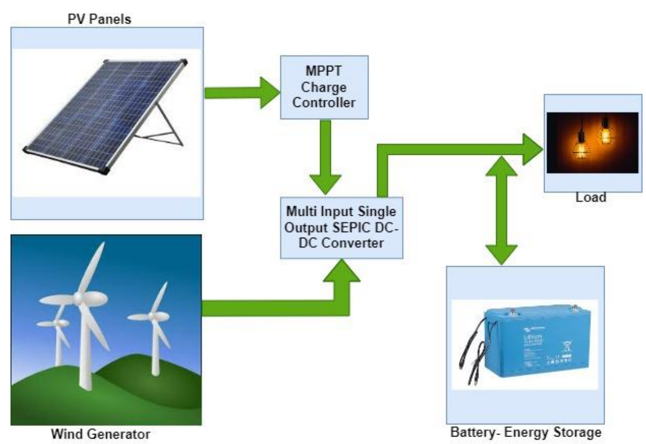

Fig. 1. Simplified Schematic Diagram of the System

A. *Operating Principle of the Proposed Converter*

To receive a better output from the system, a highly efficient DC-DC converter is needed for the DC loads. There are many other converter setups, but the SEPIC converter remains to be the best option here. SEPIC, unlike the Boost and Buck converters, has two operational modes which can give both boosted and bucked output depending on the duty cycle. Additionally, unlike the Ćuk and Buck-Boost converters, it does not provide output with reverse polarity. To tackle the reverse polarity issue, a new rectifier circuit needs to be deployed which isn't required in the case of the SEPIC which helps to reduce the circuit size. On the other hand, SEPIC has continuous input current and less reflected ripple which is absent in the ZETA converter. In this paper, a modified Multi Input Single Output (MISO) SEPIC converter is used to facilitate more than one decentralized renewable energy source for supplying power to the loads. A simplified visual representation of the suggested topology is shown in Fig. 2. From the diagram, it can be seen that the suggested converter can take up to n number of sources into the input terminal. This proposed converter plays a significant role by ensuring efficiency as unlike the conventional single-input converter, it utilizes fewer elements in the circuit system. As a result, the MISO converter reduces the amount of power loss during the conversion. The relation between the output and input voltage of the MISO converter can be presented by the below equations [14].

$$V_o = \frac{D_2 V_2 + (D_2 - D_1) V_1}{1 - D_1} \tag{1}$$

Here, V_o stands for the output voltage and V_1 & V_2 are two input voltage sources to the converter. D_1 and D_2 are the duty cycle of the voltage sources V_1 and V_2 respectively. The converter works as uni-directional in nature and power flows totally from the source side to the load side.

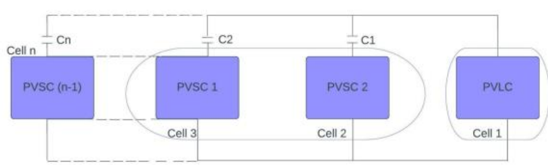

Fig. 2. Suggested Topology of MISO SEPIC DC-DC Converter [14]

III. Prospect of Solar and Wind Energy in Bangladesh

Geographical location allows the country to harness solar power more effectively as the country receives annually a handsome amount of solar radiation. Due to its proximity to the sun, solar energy is greater towards the equator. The equatorial part of the globe receives sunlight in a vertical direction. Countries located on or near the equator receive the sun's rays most. Bangladesh is 1640 miles from the equator and situated at a latitude of 23.710 and a longitude of 90.40722. In Bangladesh, there are 2,500 hours of sunshine per year. And, the country's solar radiation absorption is 4-6 kWh/m^2/day approximately on average [15]. Estimating solar resources can be done with ground-based sensors or satellite-based solar models. In contrast to satellite-based models, which provide data with a lower measurement frequency but a longer history, sensors on the ground often provide dependable and high-frequency data. The most important factor to take into account while constructing a PV power system is GHI (Global Horizon Irradiation). Fig. 3 presents the solar energy received by a particular part (Hatiya) of the country per month of a single year.

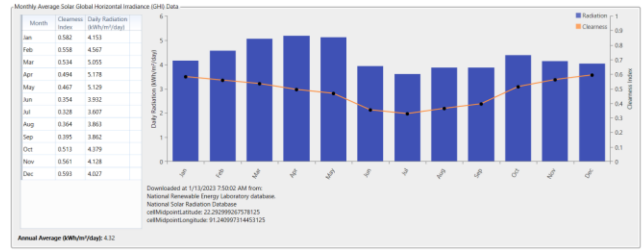

Fig. 3. Solar Irradiance Received by Hatiya, Bangladesh

For analysis in this paper, an insular island named Hatiya is considered. Hatiya is an island part of the Noakhali district located along the southern coast of Bangladesh. This island has a population of more than 450000 according to 2022 census data, detached from the mainland [16]. Due to the remote position from the mainland, support from the national grid has remained a major issue for the locals of the region. With more or less 4.5kWh/m^2/day irradiance, the region boasts excellent conditions for solar PV [17]. On the other hand, due to the uneven heating of the atmosphere caused by the sun and the rotating planet, Bangladesh's extensive coastline is ideal for wind energy. For being a coastal region, Hatiya is also in a favorable position for harnessing wind power as it receives more wind compared to the other part of the country. Fig. 4 shows the annual monthly wind speed data for a specific region (Hatiya) of the country.

Fig. 4. Wind Speed Data of Hatiya, Bangladesh

Wind speed varies with the hub height's altitude. The following equation can be used to calculate wind speed at a specific height [21],

$$\frac{V_z}{V_{ref}} = \frac{h\alpha}{h_{ref}} \tag{2}$$

Where V_z is the average wind speed at the height of h meter, V_{ref} is the average wind velocity at reference height, h is the height where the velocity of wind is to be calculated in meters, h_{ref} is the reference height in meter, and α is the dimensional constant (0.1≈0.4). According to the study's conclusion, "preliminary results demonstrate that, for wind speeds of 5.75 to 7.75 meters per second (m/s), there are more than 20,000 square kilometers of land with a gross wind potential of over 30,000MW." The study was funded by the United States Agency for International Development (USAID) [18].

IV. Software Simulation

The software simulation is divided into two parts, one is in MATLAB/Simulink environment, and another one is in HOMER. The main agenda of Simulink simulation is to prove the feasibility of the proposed topology, and HOMER is used to determine the technical and economic practicability.

A. System in MATLAB/Simulink

The proposed topology has been modeled in the Simulink environment to justify its feasibility. Actual Solar PV systems and wind turbines are equivalent to Simulink Model [20]. Simulations at various Irradiance and Temperature values obtained from SWERA are used to validate the PV model [19]. Fig. 5 shows the simulation of the topology in the Simulink.

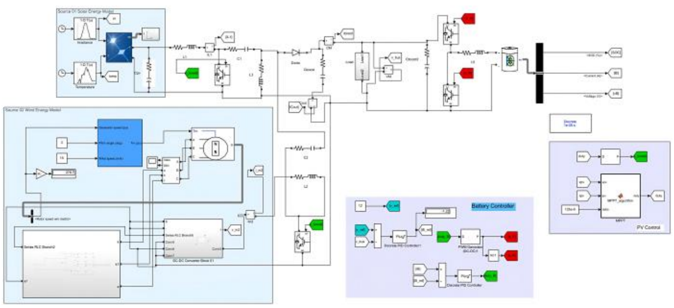

Fig. 5. MATLAB/Simulink Modelling of the Hybrid Topology

In the simulation, Source-1 is the PV panels, and Source-2 is the wind turbine. 1 Canadian Solar CS6X-310P module for PV Array has been used. Along with the PV modules, a block of an MPPT controller is placed, which works as a voltage regulator. MPPT controller helps the system from being harmed due to the variable output from the solar modules due to variable solar irradiance. The MPPT algorithm is made in such a way that it will stabilize the output from the panel to 12V during the operational mode. Between the load and source terminals, a modified SEPIC converter is placed. The output of a PV panel is highly volatile as it depends on solar radiation and temperature. Next, the second source, a wind turbine, is also heavily dependent on wind speed. In this simulation, the wind speed of 5 m/s is set, which will rotate the turbine and produce electricity from there. Since the output voltage from the turbine is directly proportional to the rate of wind velocity, it needs to be stabilized. In the output segment of the turbine, a closed loop feedback system-based converter is put so that the turbine gives almost a constant output of 12V. Electricity is produced here by converting the mechanical energy in the turbine. Both of these sources' outputs are fed into the modified SEPIC converter, which supplies the load. Along with the load, batteries as the energy storage device is installed. Batteries will be charged with the excess power generated from the source. And during the situation when both of the sources are out of phase, the batteries will discharge to meet the energy demand. A battery controller circuit is also put with the batteries to control the charging and discharging phenomena. Depending on the load demand, the number and size of the panel and wind turbines can be increased. In the result analysis part, the output part of the simulation will be discussed.

B. Analysis of the System in HOMER

The proposed topology is created in the HOMER environment for analysis and feasibility testing. For the simulation in HOMER, an assumption is made that the demand for a Hatiya-based small community is 165.59kWh/day and peak demand is 30.44kW. Here for simulation in HOMER, Canadian Solar CS6X-325P solar panel and Bergey Excel 6-R wind turbine models are used. The rated capacity of a single unit is 0.325kW and 6kW, respectively. Figs. 6 and 7 depict the hybrid system model from Homer and the seasonal load profile of the assumed community.

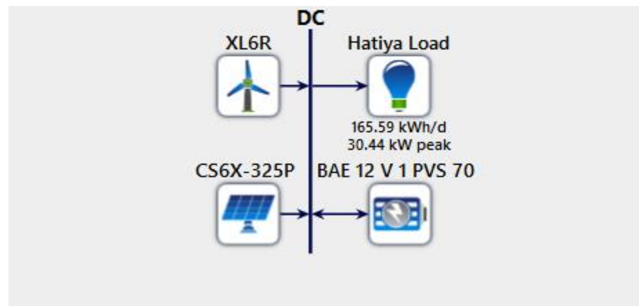

Fig. 6. Model of the Hybrid Topology in HOMER

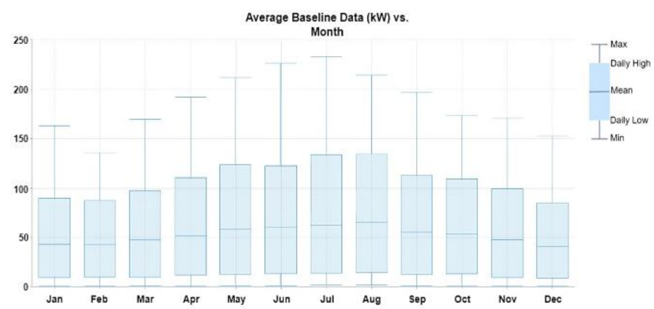

Fig. 7. Seasonal Load Profile of assumed community in Hatiya

Renewable energy is based on an hourly basis due to the highly volatile parameters used in solar PV and wind turbines. All the loads used in this proposed system assume to be DC in nature.

V. RESULT AND COST ANALYSIS

Similar to the simulation part, the result analysis section is also split into two parts. One part is for results obtained from Simulink simulation, and another is for HOMER. In the result analysis, part of Simulink, power data from PV and wind turbine individually and load side power is presented.

A. Simulink Results

As earlier mentioned, modeling in Simulink is based on only one piece of PV panel, wind turbine, and storage element. Depending on the load profile and demand, the number of these key elements needs to be increased. The Simulink analysis gives insights into the practical usability of the topology. Since Bangladesh is located near the tropical region, the sun rises at around 05:00 am, and from Fig. 8, it can be seen that from 05:00 am to 04:00 pm, the panel starts to produce power. From 10:00 am to 12:00 pm, the sun gives the maximum radiation. Hence, the PV panel gives the peak output this time. After 5:00 pm, the output power from the panel is completely nil.

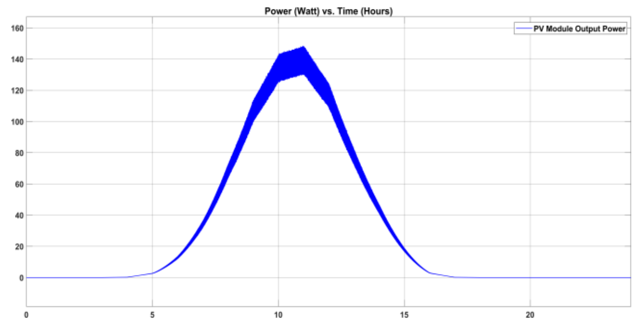

Fig. 8. Power Obtained from Photovoltaic Panel (Time in 24-hours Format)

Fig. 9 shows a constant power output from the turbine. Unlike the solar panel where variable temperature and irradiation data are used, a constant wind speed is fed into the turbine system in the simulation. Due to this, power output from the turbine is almost constant, and since the turbine can work both day and night, power can be attained all day long. Fig. 10 delimitates the total power supplied to the load terminal. From the graph, it can be expressed that, when the PV power is almost zero, the load gets support from the wind turbine alone. When the PV power is non-zero, the load starts to get combined power from both of the sources. During the peak sun hour, the aggregate of power from the sources is the highest of all.

Fig. 9. Power Obtained from Wind Turbine (Time in 24-hours Format)

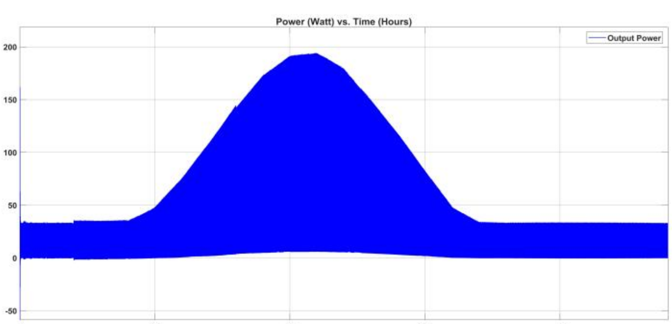

Fig. 10. Power at Load Terminal (Time in 24-hours Format)

B. HOMER Results

HOMER Analysis Tool gives the optimal solution for creating a microgrid based on Hybrid Renewable sources. According to the HOMER simulation, in total, 124 Photo Voltaic Panels, 2 Wind turbines, and 767 pieces of batteries are needed to mitigate the demand of the assumed community. The monthly production of electricity data can be seen in Figure 11. In the diagram, XL6R is for Bergey's wind turbines, and CS6X-325P is for Canadian Solar's PV panels. During the middle phase of the year, wind speed increases in Bangladesh, resulting in an increasing share of the total production.

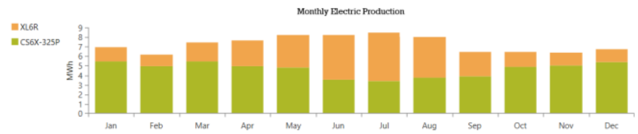

Fig. 11. Monthly Electricity Production (x-axis Month, y-axis Electricity)

Figure 12 delineates the cash flow chart of the whole system. Each bar on the chart indicates the total amount of funds that came in or went out over the course of a certain year. The first bar, for year zero, displays the system's capital cost and the last bar shows the salvage cost in the 25th year. Initially, the whole system needs approximately 63448 USD to be built. From the chart, it's also noticeable that there will be a small amount of maintenance cost every year. The system is calculated for 25 year lifetime period. In the 10th and 20th years, there will be a replacement charge for the batteries and wind turbines.

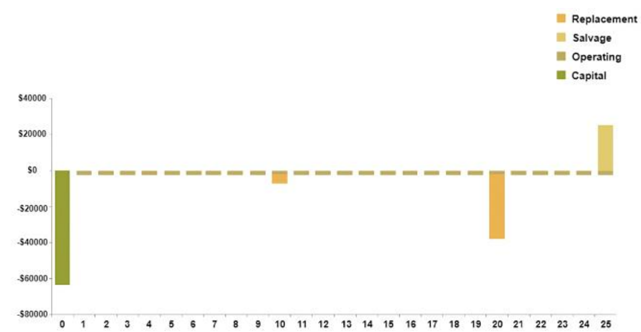

Fig. 12. Cash Flow Chart of the Proposed System (Number of Years vs. Cost)

C. Cost Analysis

Table I presents the optimum costs of the key components in the system. PV panels, wind turbines and batteries are regarded as key components here. Apart from the key component, other miscellaneous costs should be added up. Other miscellaneous cost includes the land price for setting up the plant, DC-DC converter and its elements, etcetera which can be estimated at roughly 10000 USD. The cost in the table is for 25 years which is the total lifetime of the system.

TABLE I. COST SUMMARY OF KEY ELEMENTS

Name of Components	*Cost in USD*	*Cost in BDT, 1USD=105 BDT*
PV Panels (Canadian Solar CS6X- 325P)	43607	4578735
Wind Turbine (XL-6R)	47102	4945710
Energy Storage Device	10146	1065330
Total Cost	100855	10589775

VI. CONCLUSION AND FUTURE WORK

From the perspective of Bangladesh, hybrid renewable energy sources can be a vital solution for its rural underdeveloped area deprived of on-grid energy. Separately, single renewable energy sources like PV panels or wind turbines are less efficient as they cannot be fully operated in all weather conditions at the same time. For example, in stormy conditions, PV panels will not give the desired output, but the turbines can. So, hybrid topologies can compensate for each other in the system. Moreover, batteries are used for backup when there will not be enough power generated from the sources. During peak production hours, the sources will always generate more power than the load demand, and this excess power will be stored in storage devices for emergency situations. This paper discussed the viability of a hybrid renewable energy source-based topology for an insular island in the Bay of Bengal. MATLAB/Simulink is used to find the practicability of the proposed design, and HOMER gives an economically optimal solution to build the system. In engineering design, economic feasibility is a mandatory checklist to be fulfilled and HOMER ensures that for the proposed design. Such kind of model can reduce the demand for fossil fuel-based plants which can ultimately prove to be a savior for nature. In the future, more renewable energy sources can be added to the system, such as biomass energy or tidal energy. In that case, the converter can be further modified so that it can facilitate more than two sources on the input side. Thus, the weather-dependent constraint can be minimized further.

REFERENCES

[1] "Total energy consumption," Enerdata. [Online]. Available: https://yearbook.enerdata.net/total-energy/world-consumption-statistics.html. [Accessed: 17-Jan-2023]

[2] "Gas and coal reserve & production - hcu.portal.gov.bd." [Online]. Available: http://hcu.portal.gov.bd/sites/default/files/files/hcu.portal.gov.bd/monthly_report/2c8c8d11_4355_4d82_9fd5_4d3982c7a91c/2020-06-18-20-27-9315dbc07707f4467d06d63c7425d992.pdf. [Accessed: 17-Jan-2023]

[3] "Power and Energy- mof.portal.gov.bd."[Online]. Available: https://mof.portal.gov.bd/sites/default/files/files/mof.portal.gov.bd/page/f2d8fabb_29c1_423a_9d37_cdb500260002/19_BER_22_En_Chap10.pdf [Accessed: 17-Jan-2023]

[4] "Solar and wind power potential in Bangladesh 2022," Energy Tracker Asia, 12-May-2022. [Online]. Available: https://energytracker.asia/solar-and-wind-power-potential-in-bangladesh/. [Accessed: 17-Jan-2023]

[5] P. K. Halder, N. Paul, M. U. H. Joardder, M. Sarker, "Energy scarcity and potential of renewable energy in Bangladesh, Renewable and Sustainable Energy Reviews, Volume 51, 2015, Pages 1636-1649, ISSN 1364-0321, https://doi.org/10.1016/j.rser.2015.07.069

[6] M.S. Ismail, M. Moghavvemi, T.M.I. Mahlia, "Design of an optimized photovoltaic and microturbine hybrid power system for a remote small community: Case study of Palestine", Energy Conversion and Management, Volume 75, 2013, Pages 271-281, ISSN 0196-8904, https://doi.org/10.1016/j.enconman.2013.06.019.

[7] T. Mahmud, S. M. A. Rakeen, A. U. Araf, N. Ahmed and A. K. M. Abdul Malek Azad, "Design and Accuracy Assessment of a Multi-Input Single Ended Primary Inductor Converter (SEPIC) for Highly Efficient Output from Hybrid Sources of Renewable Energy," 2022 IEEE International Systems Conference (SysCon), Montreal, QC, Canada, 2022, pp. 1-8, doi: 10.1109/SysCon53536.2022.9773908.

[8] M. T. Imran, A. N. Barshan, S. M. Shams, R. Tajwar, L. Zahin and A. A. M. Azad, "Extracting Atmospheric Water using Peltier Effect Powered by Solar Energy with Contribution from Piezo-Materials," 2022 IEEE International Systems Conference (SysCon), Montreal, QC, Canada, 2022, pp. 1-7, doi: 10.1109/SysCon53536.2022.9773876.

[9] C. Li, D. Zhou, H. Wang, Y. Lu and D. Li, "Techno-economic performance study of stand-alone wind/diesel/battery hybrid system with different battery technologies in the cold region of China", Energy, Volume 192, 2020, 116702, ISSN 0360-5442, https://doi.org/10.1016/j.energy.2019.116702.

[10] M.J. Khan, M.T. Iqbal, "Pre-feasibility study of stand-alone hybrid energy systems for applications in Newfoundland", Renewable Energy, Volume 30, Issue 6, 2005, Pages 835-854, ISSN 0960-1481, https://doi.org/10.1016/j.renene.2004.09.001.

[11] T. Ma, H. Yang and L. Lu, "Study on stand-alone power supply options for an isolated community", Electrical Power and Energy Systems 65 (2015) 1–11

[12] S. Bhakta, V. Mukherjee and B. Shaw, "Techno-economic analysis of standalone photovoltaic/wind hybrid system for application in isolated hamlets of North-East India", JOURNAL OF RENEWABLE AND SUSTAINABLE ENERGY 7, 023126 (2015), https://doi.org/10.1063/1.4918792.

[13] J. B. Fulzele and S. Dutt, "Optimum Planning of Hybrid Renewable Energy System Using HOMER", International Journal of Electrical and Computer Engineering (IJECE), Vol. 2, No. 1, February 2012, pp. 68~74. ISSN: 2088-8708

[14] C. Anuradha, N. Chellammal, M. Saquib Maqsood and S. Vijayalakshmi, "Design and Analysis of Non-Isolated Three-Port SEPIC Converter for Integrating Renewable Energy Sources", Energies, vol. 12, no. 2, p. 221, 2019. Available: 10.3390/en12020221

[15] I. Jerin, "Bangladesh: Favoured Land for Solar Energy", Daily Sun, Dec. 31, 2017. [Online]. Available: https://www.daily-sun.com/printversion/details/278725/Bangladesh:-Favoured-Land-for-Solar-Energy [Accessed: 21-Dec-2022]

[16] "Local health bulletin- 2022 - app.dghs.gov.bd." [Online]. Available: https://app.dghs.gov.bd/localhealthBulletin2016/publish/publish.php?org=10001037&year=2016. [Accessed: 17-Jan-2023]

[17] "Solar Photovoltaic Power Potential by Country", [Online]. Available: https://www.worldbank.org/en/topic/energy/publication/solar-photovoltaic-power-potential-by-country

[18] "Bangladesh bets big on wind energy to curb climate change" , Dhaka Tribune, Jan. 08, 2022. [Online]. Available: https://www.dhakatribune.com/nation/2022/01/08/bangladesh-bets-big-on-wind-energy-to-curb-climate-change [Accessed: 17-Dec-2022]

[19] M. Hussain, M. S. K. Khadem and H. R. Ghosh, "Final Report of Solar and Wind Energy Resource Assessment (SWERA)-Bangladesh Project, "Published by Renewable Energy Research Centre (RERC) University of Dhaka, Bangladesh. Supported by United Nations Environment Programme (UNEP) and Global Environment Facility (GEF) (2007).

[20] C. G. Balinavar, R. N. Bhairavkar, S. Lotos, S. G. Bhumkar, Dr. V. W. Bhatkar, "Design and Simulation of Solar Powered Vapour Compression Refrigeration System", International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE), Vol 6, Issue 8, August 2021, ISSN (Online) 2456-1290

[21] "Bangladesh Meteorological Department." [Online]. Available: http://www.bmd.gov.bd/. [Accessed: 17-Jan-2023]