Design and Analysis of Optimized Hybrid Energy System for a Grid-Connected Swarna Island, Bangladesh

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Abstract - *The research work investigates the potential of solar, wind, and diesel generators, optimizes the system's performance, and addresses utility integration challenges. Cost-benefit analyses are utilized to evaluate economic viability, while environmental impact assessments are employed to examine sustainability. Through an examination of the deployment of large-scale solar initiatives, wind turbines, and diesel generators in Bangladesh, this research makes a substantial scholarly contribution towards the advancement of sustainable energy. The article proposes the establishment of a grid-connected solar photovoltaic power plant featuring a capacity of 60 megawatts (MW). This development would capitalize on the abundant solar energy in the area and provide a substantial boost to the local power infrastructure. The aim of this study is to develop a grid-connected solar photovoltaic power facility with a capacity of 200 megawatts (MW), a 566 KW wind turbine, and a 200 KW diesel generator for Swarna Island, Bangladesh.*

Key Words: Solar, Photovoltaic, Cost effective, Renewable energy, Sustainable technology, Simulation, Wind, Generator etc.

1.INTRODUCTION

The utilization of renewable energy sources is becoming increasingly important in addressing the rising worldwide power demands. Solar photovoltaic (PV) and wind turbine power plants are regarded as favourable examples of renewable energy due to their capacity to generate electricity while simultaneously mitigating the release of greenhouse gases [9] [11]. The objective of the proposed project is to design and construct two power plants: 566 KW wind turbine power plants and 60 MW grid-connected solar photovoltaic power plants. These plants will harness the copious solar and wind energy resources of the region while also making a substantial contribution to the local power infrastructure [10]. Swarna Island is located in a secluded region of the Hatiya Upazila, Noakhali District, Chittagong Division, Bangladesh. Strategic training base management of the facility is entrusted to the Bangladesh Army. Located in the estuary of the Meghna, the island comprises a total area of 360 m^2 (square kilometres). The coordinates of its longitude and latitude are 91.299°E and 22.519°N, respectively [1].

1.1 Location

In the Bay of Bengal, Swarna Island, alternatively referred to as Jahaijar Char, is an inhabited island. It is situated in the Chittagong Division of the Noakhali District of the Hatiya Upazila in Bangladesh. The Bangladesh Army administers the facility as a strategic training base. The island is situated in the estuary of the Meghna and encompasses an area of 360 square kilometers [2].

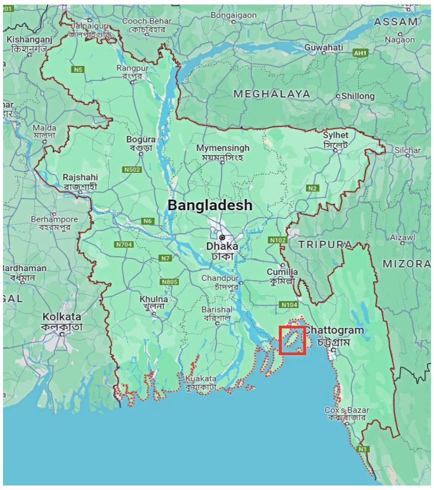


Fig-1: Map of Bangladesh (marked Swarna Island) [3]

1.2 Power Plant location

Considering its final location, the satellite view significantly simplifies the review and assessment of the numerous potential sites for the power plant that will be necessary for this undertaking. Swarna Island has a significantly greater quantity of trees than any other location in Bangladesh. It helps in the preservation of natural disasters and ecological systems.

Furthermore, specific areas are inhospitable to tree growth because of the presence of saltwater. The aforementioned sites are optimal options for the development of power plant.

Fig-2: Satellite view of study area Swarna Island [4]

2. LOAD PROFILE OF SWARNA ISLAND

Swarna Island, which is often referred to as Jahaijar Char, is a populated island located in the Bay of Bengal. The location mentioned is Hatiya Upazila, which falls under the Noakhali District in the Chittagong Division of Bangladesh. In 2013, the Island changed its name to Swarna Island. Additionally, the Bangladesh Army took charge of the island's administration. Their responsibilities included developing the island, establishing government services, and maintaining security. According to the information provided, on Swarna Island on average, only 550 people reside in this area. In comparison, there is a lower population on the island. The island is made up of 3 Helipad maintaining control rooms, 3 mosques, 4 hotels, 25 houses, 10 shops, 3 Hospitals, 3 Military maintenance buildings, 8 cyclone centers, 10 dairy farms, and 5 fishing farms.

2.1 Load profile of hotels

Table-1: Estimation of the electrical load for each room in a hotel

Appliances	Quantity	Capacity (in watt)	Average operational hours everyday	Load (in KW)	KWh per day
Light	4	30	7	0.12	0.84
Fan	2	75	10	0.15	1.5
TV	1	50	3	0.05	0.15
			Total	0.32	2.49

2.2 Load profile of Mosque

Table-2: Estimation of the electrical load for Mosque

Appliances	Quantity	Capacity (in watt)	Average operational hours everyday	Load (in KW)	KWh per day
Lights	20	30	7	0.6	4.2
Fan	15	75	7	1.1257	7.875
			Total	1.725	12.075

2.3 Load profile for local people usages

Table-3: Estimation of the electric load for local people usages

Appliances	Quantity	Capacity (in watt)	Average operational hours everyday	Load (in KW)	KWh per day
Light	4	30	7	0.12	0.84
Fan	2	75	9	0.22	2.02
TV	1	50	4	0.05	0.2
Refrigerator	1	350	24	0.35	8.4
			Total	0.74	11.46

2.4 Load profile for helipad maintaining control room

Table-4: Estimation of the electrical load for the helipad

Appliances	Quantity	Capacity (in watt)	Average operational hours everyday	Load (in KW)	KWh per day
Light	4	30	3	0.12	0.36
Fan	2	75	3	0.15	0.45
			Total	0.27	0.81

2.5 Load profile for local shops

Table-5: Estimation of the electrical load for local shops

Appliances	Quantity	Capacity (in watt)	Average operational hours everyday	Load (in KW)	KWh per day
Light	2	30	7	0.06	0.42
Fan	2	75	10	0.15	1.5
			Total	0.21	1.92

2.6 Load profile for military maintenance buildings

Table-6: Estimation of the electrical load for military buildings

Appliances	Quantity	Capacity (in watt)	Average operational hours everyday	Load (in KW)	KWh per day
Light	25	30	7	0.75	5.25
Fan	15	75	10	1.12	11.25
Computer	2	200	6	0.4	2.4
Refrigerator	1	350	24	0.35	8.4
			Total	2.625	27.3

2.7 Load profile for dairy and fishing farms

Table-7: Estimation of the electrical load for farms

Appliances	Quantity	Capacity (in watt)	Average operational hours everyday	Load (in KW)	KWh per day
Light	20	30	6	0.6	3.6
Fan	12	75	8	0.9	7.2
Water pump	2	1500	4	3	12
Exhaust fan	6	45	6	0.27	1.62
			Total	4.77	24.42

2.8 Load profile for hospital

Table-8: Estimation of the electrical load for hospital

Appliances	Quantity	Capacity (in watt)	Average operational hours everyday	Load (in KW)	KWh per day
Light	50	30	7	1.5	10.5
Fan	40	75	10	3	30
Refreezes	2	350	24	0.7	16.8
Clinical machine	5	80	5	0.4	2
Microscope	8	20	8	0.16	1.28
			Total	5.76	60.58

2.9 Load profile for cyclone center

Table-9: Estimation of the electrical load for cyclone center

Appliances	Quantity	Capacity (in watt)	Average operational hours everyday	Load (in KW)	KWh per day
Light	20	30	5	0.6	3
Fan	15	75	5	1.12	5.6
			Total	1.725	8.625

Loads are considered 2424.25 KWh/day and peak load 348.08 KW/day.

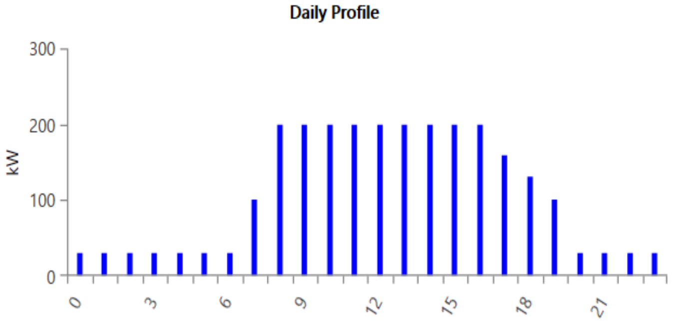


Chart-1: Daily load curve

3. ENERGY ELEMENT

A variety of energy-related components are necessary for the design and analysis of a hybrid power system for the remote, offshore island of Swarna. Batteries, wind turbines, solar photovoltaics, diesel generators, rectifiers, and inverters are all considered in order to validate the proposed hybrid power system.

3.1 Solar PV

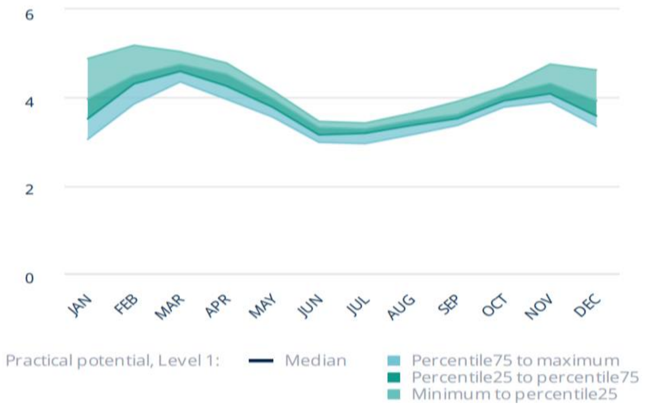


Chart-2: Monthly variation of photovoltaic power output [5]

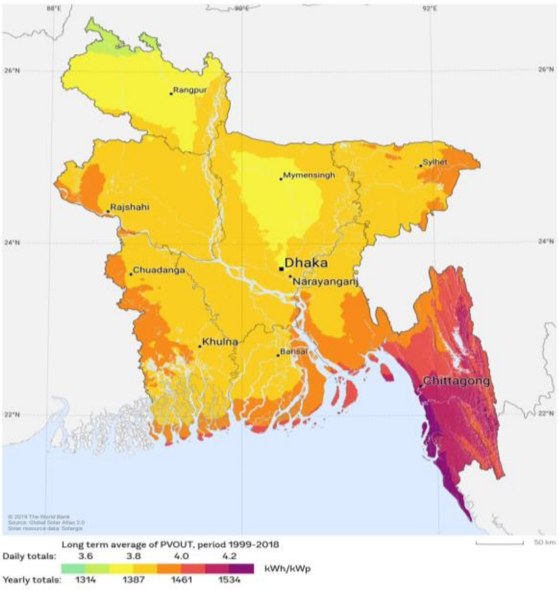


Fig-3: Photovoltaic power potential in Bangladesh [5]

Table-10: Site info data from simulation (per day) [7]

Direct normal irradiation	3.326 KWh/m^2
Global horizontal irradiation	4.818 KWh/m^2
Diffuse horizontal irradiation	2.479 KWh/m^2
Global tilted irradiation at optimum angle	5.141 KWh/m^2
Optimum tilt of PV modules	23/180°
Air temperature	26.1°C
Terrain elevation	-5 m

Annual averages are 0.246 GWh per day or 5.141 KWh/m^2 per day (total photovoltaic power output and global tilted irradiation).

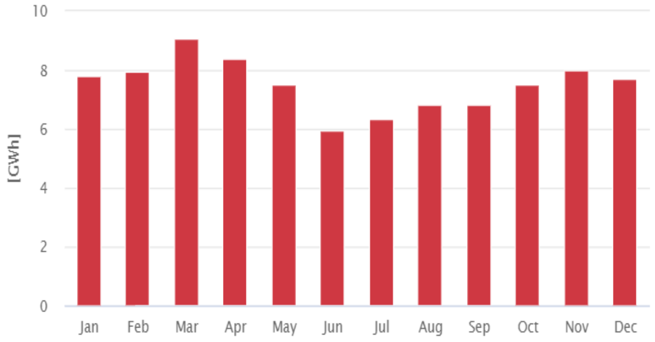
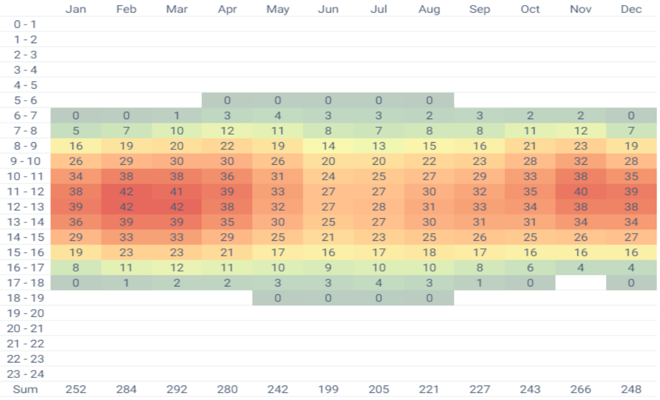


Chart-3: Photovoltaic power output (monthly averages) [6]



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0 - 1												
1 - 2												
2 - 3												
3 - 4												
4 - 5												
5 - 6				0	0	0	0	0				
6 - 7	0	0	1	3	4	3	3	2	3	2	2	0
7 - 8	5	7	10	12	11	8	7	8	8	11	12	7
8 - 9	16	19	20	22	19	14	13	15	16	21	23	19
9 - 10	26	29	30	30	26	20	20	22	23	28	32	28
10 - 11	34	38	38	36	31	24	25	27	29	33	38	35
11 - 12	38	42	41	39	33	27	27	30	32	35	40	39
12 - 13	39	42	42	38	32	27	28	31	33	34	38	38
13 - 14	36	39	39	35	30	25	27	30	31	31	34	34
14 - 15	29	33	33	29	25	21	23	25	26	25	26	27
15 - 16	19	23	23	21	17	16	17	18	17	16	16	16
16 - 17	8	11	12	11	10	9	10	10	8	6	4	4
17 - 18	0	1	2	2	3	3	4	3	1	0		0
18 - 19					0	0	0	0				
19 - 20												
20 - 21												
21 - 22												
22 - 23												
23 - 24												
Sum	252	284	292	280	242	199	205	221	227	243	266	248

Chart-4: Photovoltaic power output in hourly profile (MWh) [6]

The Sun's apparent arc-like trajectory across the sky on a daily and seasonal basis, which is observed as the Earth revolves and orbits the Sun, is commonly known as the Sun path. During a specific season and at a given latitude, the amount of daylight and duration of daylight are influenced by the Sun's path [12]. The efficiency of solar energy systems and the heat accumulation in buildings are both significantly influenced by the Sun's relative position. Location-specific information on the sun's path and climatic conditions is necessary for making economic decisions concerning solar collector area, orientation, landscaping, summer shading, and the most cost-effective use of solar trackers [13].

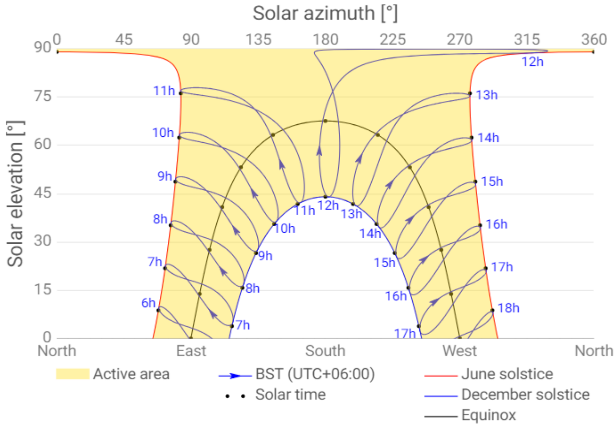


Chart-5: Horizon and sun path [6]

3.2 Wind Turbine

Table-11: Wind turbine information [7]

Turbine type	Generic 3 KW
Capacity	566 KW
Rotor diameter	125
Hub heights	100 m
Power control system	Pitch
Wind speed (annual)	4.5 m/s
Air density	1.225 Kg/m^3

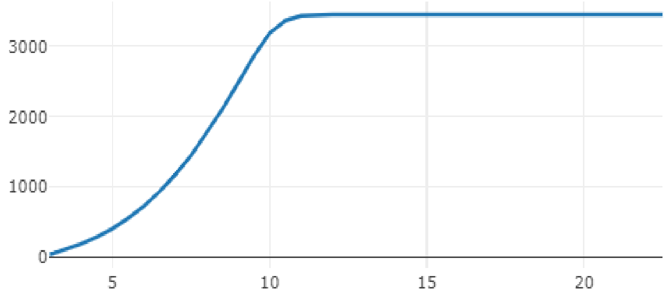


Chart-6: Power curve [7]

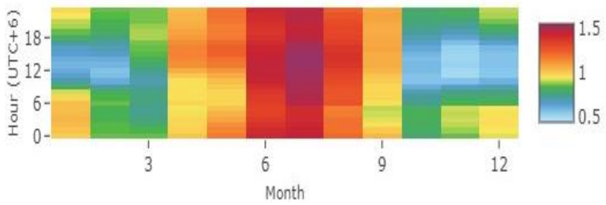


Chart-7: Wind speed index, hourly vs monthly (cross table) [7]

3.3 Diesel generator

The fuel graph exhibits an intercept point at 5.23 liters per hour, with a slope value of 0.236 liters per hour per kilowatt.

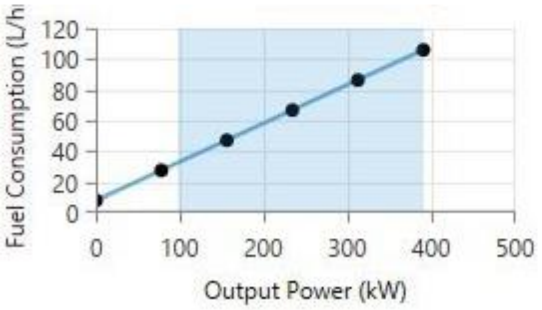


Chart-8: Fuel consumption vs output power curve [8]

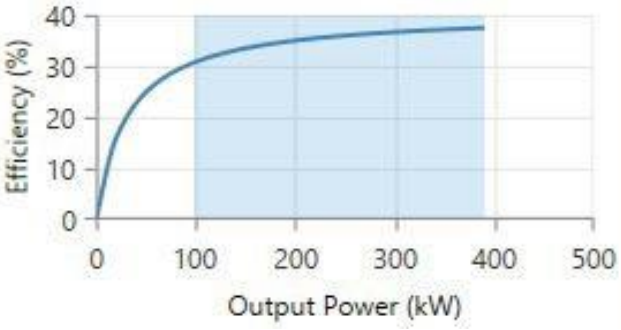


Chart-8: Efficiency vs power output curve [8]

3.4 Grid-Connected system

The selection of the layout for a specific area is determined by economic, geographical, and technical considerations. The centralized DC-bus architecture involves the conversion of AC power from an energy source, such as a wind generator, into DC power using rectifiers. The converted DC power is then provided to the main DC bus bar. An inverter is employed to supply the alternating current (AC) grid with power from the direct current (DC) bus. The centralized AC-bus architecture involves the installation of power sources, batteries, and power electronic equipment in a single location. These components are then connected to a main AC bus bar, which is further connected to the grid. This system operates in a centralized manner, where the electricity is generated by all energy conversion units, and the battery is supplied to the grid through a single point. Distributed ac-bus architecture: The power sources can be put at different locations and do not require a connection to a central bus. The sources are dispersed across many places and subsequently linked to the grid individually. Each power source is individually conditioned to match the needed form for the grid.

4. COST ANALYSIS

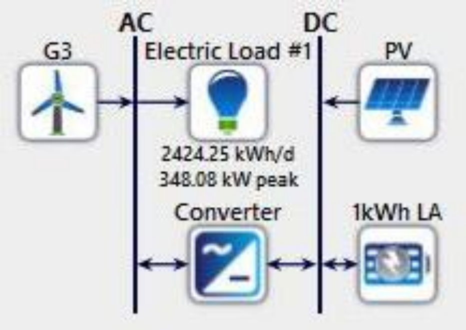


Fig-4: Schematic diagram of system-1 [8]

According to simulation data from HOMER Pro, the peak demand is 348.08 KW. The lead acid battery with a capacity of 1 kilowatt-hour is linked to a direct current electrical bus. [8]. The annualized nominal capacity of the battery is 171,153 KWh, or 4,593 KWh. Wind turbine operation and maintenance expenses amount to 1000509.51 (BDT). The cost of turbine investment capital is 100050951.00 (BDT). Annual production from wind turbines amounts to 345,600 KWh [8].

The photovoltaic solar sector generates 2,790,029 KWh of electricity annually at a capital cost of 53,61,77,444.25 (BDT) [8].

System-1 incurs a net power cost of 748.7 crore (BDT) and a total energy cost of 161.4 crore (BDT). Initial capital, when operation costs are accounted for, amounts to 804.8 crore (BDT) [8].

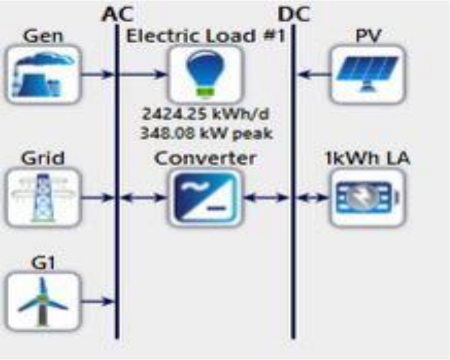


Fig-5: Schematic diagram of system-2 [8] [14]

The total quantity of capital expenditure for system-2 is 16.4 crore (BDT). Although there are increased operational and maintenance expenses when compared to system-1, there is a substantial improvement in power delivery efficiency. System-2 experiences considerably superior power delivery as a result of the diesel generator. The diesel generators, which are employed for the duration of the power facility's life cycle, have an estimated cost of 7.8 million (BDT).

Table-12: Cost analysis for energy elements

Energy elements	Capital cost (BDT)	Replacement cost (BDT)	Operational and maintenance cost (BDT)	Lifetime
Diesel generator	18,000	16,000	500	15,000 hours
Solar PV	85,000	75,000	500	25 years
Wind turbine	120,000	100,000	2400	15 years

Table-13: Cost summary for system-1

Components	Capital cost (BDT)	Replacement cost (BDT)	Operational and maintenance cost (BDT)	Salvage cost (BDT)	Total cost (BDT)
Solar PV	31633333.34	0.00	252737.6	0.00	31886070.9
Battery	42160000.00	60745840.02	53894629.56	-2786667.9	154013802
Converter	9081710.84	324814.7	8292536.5	-604582.9	17094479.1
Wind-turbine	72960000.00	0.00	19430701.36	0.00	92390701.4
Total	155835044.00	61070654.7	81870605	-3391250.8	295385053

Table-14: Cost analysis of system-2 [16]

Components	Capital cost (BDT)	Replacement cost (BDT)	Operational and maintenance cost (BDT)	Cost of fuel (BDT)	Salvage cost (BDT)	Total cost (BDT)
Diesel Generator	7200000.00	0.00	50877751.5	7805314.79	-996612.8	64886453.5
Solar PV	31403690.9	0.00	250902.86	0.00	0.00	31654593.8
Battery	53280000.00	52250227.14	68109721.62	0.00	-735083.68	172904865.00
converter	7098482.38	2538813.16	6481602.04	0.00	-472553.34	15646344.2
Wind-turbine	65280000.00	0.00	17385364.38	0.00	0.00	82665364.4
Total	164262173.00	54789040.3	143105342.00	7805314.79	-2204249.82	367757621.00

5. EMISSION ANALYSIS

Alternative systems exhibit a higher degree of sustainability in comparison to the diesel generator-based power system. The total emissions for this specific configuration are as follows: a. CO_2 (1.9 tons annually), b. CO (13.3 kg annually), c. Unburned Hydrocarbons (1.09 kg annually), d. Particulate Matter (0.08 kg annually), e. SO_2 (6.4 kg annually), and f. Nitrogen Oxides (7.8 kg annually) [15].

6. CONCLUSIONS

Electrical power's uninterrupted accessibility has a substantial impact on the overall quality of life. The provision of electricity to remote regions via grid-connected conventional generation systems presents a formidable challenge. The primary objective of this research paper is to conduct a comparative analysis in order to suggest viable designs for connected grid and hybrid electric power generation systems on remote islands, with a particular emphasis on Swarna Island in Bangladesh. The aim of this research is to investigate and assess a range of alternatives for the efficient and sustainable production of electricity, taking into account the distinct obstacles and limitations encountered by these remote island communities. Through an analysis of various methodologies and technologies, this article attempts to offer insightful observations and suggestions regarding the construction of dependable and precise power systems in such remote areas. The integration of wind turbines with solar photovoltaic (PV) systems has been recognized as a prospective avenue for generating renewable energy for System-1. Regarding system-2, which is a hybrid power generation configuration, the wind turbines, solar photovoltaic (PV) systems, and diesel generators that are being evaluated as power generation sources. The sources in question are selected on the basis of their capacity to supply a sustainable and dependable energy supply. Wind turbines produce electricity by harnessing the kinetic energy of the wind, whereas solar photovoltaic systems transform sunlight into electrical energy. Diesel generators, conversely, generate electricity through the combustion of diesel fuel. The careful and informed choice of these power generation sources is vital for ensuring that System-2 operates efficiently and effectively, thus making a significant contribution to its overall performance and sustainability. Diesel generators have historically been acknowledged as a dependable and effective source of supplementary energy. After gathering estimated demand data, a simulation is performed utilizing the HOMER software in order to ascertain the electricity generation configuration that is most economically efficient. Sensitivity analysis is an essential component in simulations, as it accounts for the inherent variability that is observed in a range of properties, including fuel cost, wind speed, solar radiation, and component costs. This research investigates the optimal values of a variety of energy-supplying sources. The aim is ascertain the optimal and most impactful amalgamation of these sources in order to fulfill the energy requirements. Through an investigation of various factors and limitations linked to each source, our objective is to ascertain the most favorable values that will yield the greatest energy output while minimizing expenses and adverse environmental effects. We anticipate that this analysis will A novel hybrid power generation system is suggested, which integrates solar photovoltaic (PV) panels, a wind turbine, a diesel generator, converters, and storage batteries. The aforementioned system showcases the capacity to generate electricity at a levelized cost that is less than the expense that inhabitants incur when utilizing a diesel generator exclusively. This research investigates the cost and performance consequences of integrating a diesel generator as a fallback in System-2, as opposed to alternative configurations. Although relatively more expensive per unit, System-2 is renowned for its enhanced safety and security features. In this research paper, we present system-2, an innovative hybrid power generation system that is designed to help address the electricity supply challenges met by Swarna Island. The principal aim of the second system is to guarantee an uninterrupted, dependable, economical, and secure power provision for the island. In order to evaluate the prospective implementation of the hybrid model configuration that has been proposed in offshore areas of comparable distances, it is crucial to undertake an exhaustive feasibility study and analysis. The purpose of this research is to assess the viability and practicability of implementing the hybrid model in such regions. Through the implementation of an exhaustive examination, it is possible to ascertain the degree to which the suggested arrangement can be effectively implemented in offshore areas that possess similar attributes.

REFERENCES

[1] Swarna Dweep. (2023, July 8). In Wikipedia. https://en.wikipedia.org/wiki/Swarna_Dweep.

[2] The Independent. Dhaka. Retrieved 2020-10-17. “Army undertakes massive development scheme at Swarna Dweep”

[3] Google Maps. (n.d.). Bangladesh on Google Maps. Retrieved December 2023, from https://maps.app.goo.gl/N3qoaFbGjmaDqmTH9

[4] Google Maps. (n.d.). Swarna Dweep on Google Maps. Retrieved Dec2023, from https://maps.app.goo.gl/9Sw18M6N6dZQ6LsS6

[5] Suri,Marcel; Betak,Juraj; Rosina,Konstantin; Chrkavy,Daniel; Suriova,Nada; Cebecauer,Tomas; Caltik,Marek; Erdelyi,Branislav. Global Photovoltaic Power Potential by Country (English). Energy Sector Management Assistance Program (ESMAP) Washington, D.C.: World Bank Group. http://documents.worldbank.org/curated/en/466331592817725242/Global-Photovoltaic-Power-Potential-by-Country

[6] Solargis. (n.d.). Global Solar Atlas. The World Bank Group. Retrieved December 23, 2023, from https://globalsolaratlas.info/detail?c=22.497332,91.307373,11&s=22.497404,91.307124&m=site&pv=ground,180,23,60000

[7] Global Wind Atlas. (n.d.). Retrieved December 24, 2023, from https://globalwindatlas.info/en

[8] Llc, H. E. (n.d.). HOMER Energy User Site- Hybrid Renewable and Distributed Generation System Design Software. Retrieved December 26, 2023, from https://users.homerenergy.com/

[9] "Largest Solar Power Plant connects to national grid with Huawei PV Solution," The Business Standard, 21December, 2020.https://www.tbsnews.net/bangladesh/energy/largest-solar-power-plant-connects-national-gridhuawei-pv-solution-1744

[10] Research gate, Design and Analyze of 20 MW Photovoltaic Solar Power Plant in Iran, https://www.researchgate.net/publication/281446622_Design_and_Analyze_of_20_MW_Photovoltaic_Solar_Power_Plant_in_Iran

[11] Monirul Islam Miska. Current Scenario of Solar Energy Applications in Bangladesh: Techno-Economic Perspective, Policy Implementation, and Possibility of the Integration of Artificial Intelligence. Energies 2023. https://doi.org/10.3390/en16031494

[12] Sun path (2023) Wikipedia. Available at: https://en.wikipedia.org/wiki/Sun_path.

[13] Calculation of sun’s position in the sky for each location on the earth at any time of day. Available at: https://www.sunearthtools.com/dp/tools/pos_sun.php#google_vignette.

[14] Baghdadi, F., Mohammedi, K., Diaf, S., & Behar, O. (2015, November). Feasibility study and energy conversion analysis of stand-alone hybrid renewable energy system. Energy Conversion and Management, 105, 471–479. https://doi.org/10.1016/j.enconman.2015.07.051

[15] Daud, A. K., & Ismail, M. S. (2012, August). Design of isolated hybrid systems minimizing costs and pollutant emissions. Renewable Energy, 44, 215–224. https://doi.org/10.1016/j.renene.2012.01.011

[16] Hoque MM, Bhuiyan I, Ahmed R, Farooque AA, sesign A. Analysis and performance study of a hybrid PV–diesel–wind system for a village Goplal Nagar in Comilla. Global J Sci Frontier Res Phys Space Sci 2012;12:13–7.