Design and Optimization of Hybrid Energy System for a Remote Area of Bangladesh

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Abstract

Bangladesh being the populated country and aspires to be a developed nation by 2041, Bangladesh is in race to generate electricity for economic emancipation. In Bangladesh, generation of electricity is mostly dependent on non-renewable fuels. Approximately 91.54% of electricity is produced from fossil fuels whereas 5.56% from import and the rest 2.9 % of power comes from the sources of renewable energy. To get clean energy, renewable energy option is the first requirement to replace the environment degradation fossil fuels. This paper demonstrated that by suitable designing of hybrid renewable energy electricity problem can be solved for remote area. The hybrid system combines photovoltaic, wind energy and biomass. This paper highlighted the HOMER software for analysing the system performance from optimization and economic aspect. By HOMER simulation, combination of Solar PV, wind and biogas are considered as best option where the NPC is BDT 299,121,664 and COE is BDT 38.071 tk/Kwh.

Keywords – *hybrid energy, HOMER, RETScreen, optimization, sensitivity analysis***.**

1. INTRODUCTION

Bangladesh being the populated country and aspires to be a developed nation by 2041, Bangladesh is in race to generate electricity for economic emancipation. Therefore, generation of electricity of Bangladesh is the main focus in recent past and as per energy division statistics, Bangladesh has made a satisfactory progress of covering 95% of the total population under electrification scheme [1]. Rural electrification is not mark high as of urban areas.

Among the rural population, a large number of people live in remote areas like the coastal areas, chars and remote villages. These people still have a dream to have access to electricity because grid connection to those remote areas is not economically feasible. So far, the main source of electricity in Bangladesh is power plants based on natural gas, coal, imported oil and hydro-electricity. Less hydroelectricity, other sources of energy are actually non-renewable and therefore they will not last longer. These non-renewable sources of energy are becoming too expensive day by day as their supplies are reducing.

GoB has targeted to generate 24,000MW by 2021 and 40,000MW by 2030 in the country [2] which is shown in fig. 1. The total electricity generation capacity of Bangladesh was 20,849.48 MW (Including Off-Grid RE) as of October 2019 [3].

Fig. 1. Power generation plan in Bangladesh (MW)

In Bangladesh, generation of electricity is mostly dependent on non-renewable fuels. Approximately 91.54% of electricity is produced from fossil fuels whereas 5.56% from import and the rest 2.9 % of power comes from the sources of renewable energy. Among the fossil fuels, around 46.29% of electricity is being produced from our gas reserve [3]. Natural gas is the main source of energy supply for the electricity and industrial sectors. Year-wise peak demand forecast in Bangladesh (MW) is shown in fig. 2.

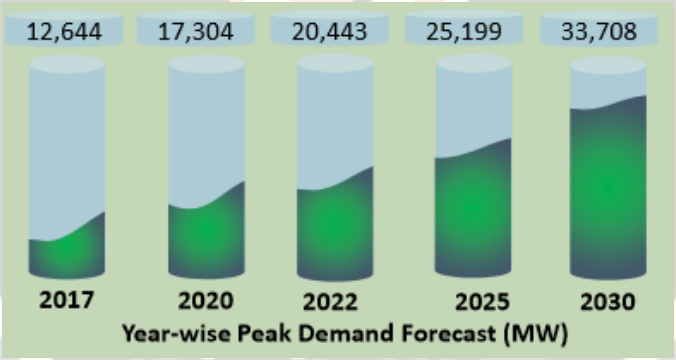

Fig. 2. Year-wise peak demand forecast in Bangladesh (MW)

In this regard renewable energy can play a significant role both for off-grid electrification in the country at present and to meet our future electricity demand. For this, a renewable energy policy is laid down in 2008 to generate 5% electricity (of the country's total demand) from renewable sources by 2015 and 10% by 2020 [4]. The government, however, has set a target of increasing the renewable energy generation capacity to 2896.68 MW by 2021, more than half of which (1470 MW) is expected to come from solar power by that time. On the other hand, wind power which is currently at an experimental stage, is expected to contribute 1153 MW by then [5]. However, according to the Sustainable & Renewable Energy Development Agency of Bangladesh (SREDA), renewable energy now contributes to approximately 2.90 % of our national energy power [3]. But unfortunately, Bangladesh is still far away from achieving its goals. However, among the renewable energy sources, solar energy has an excellent potential with an average solar radiation varies between 4 to 6.5 kWh/m^2/day. Solar energy is comparatively expensive than conventional means of electricity generation. Bangladesh possesses a favorable atmosphere for the biogas production also. The perfect temperature is approximately 35^0 for biogas. The temperature ranges from 6^0 to 40^0 here. It is not only produce gas and electricity but also gives organic fertilizer for the farmers [6].

Although wind power technology is one of the cheapest clean power options, Bangladesh still lags behind in this sector. According to, Mark D Jacobson, wind and water senior project leader of NREL, USA, generation of electricity more than 10,000 MW is expected in Bangladesh with help of wind power [5].

Bangladesh has limited hydropower potentiality due to its unfavorable topography. At present days, the only Kaptai hydropower has installed capacity of 230 MW which is the largest share of electricity generated from renewable sources. However, expert has identified more locations which are suitable for hydropower around the country.
Renewable energy may be regarded as the future of electricity production as it is replenishable and environment friendly. Renewable energy sources are plenty in nature, yet no one can depend only one renewable source as solar, wind or biomass etc. are not 100% dependable due to their fluctuating continuity over the period of time. Therefore, in recent past, due attention is given to integrate two or more renewable energy resources for generation of electricity in remote areas which is considered as suitable solution. Therefore, from the combination of solar PV, biogas, biomass, wind, tidal power, geothermal power, hydroelectricity etc sources, hybrid electricity generation is preferable.
Renewable energy scenario has not changed yet significantly due to lack of proper policy making and implementation of the policy. However, this paper portrays the significance of hybrid energy comprising of solar, wind, biogas to generate electricity to a remote area of Bangladesh.

2. Energy Scenario in Bangladesh

As on February 2019, the installed capacity of generation of electricity was 18,079 MW where 9,065 MW is generated from public sector, 7,854 MW from private sector and 1,160 MW from power trade. Including captive and renewable energy, the total installed capacity was 21,419 MW as of September 2019. However, the installed capacity of electricity production by fuel type is given in fig. 3. as on February 2019.

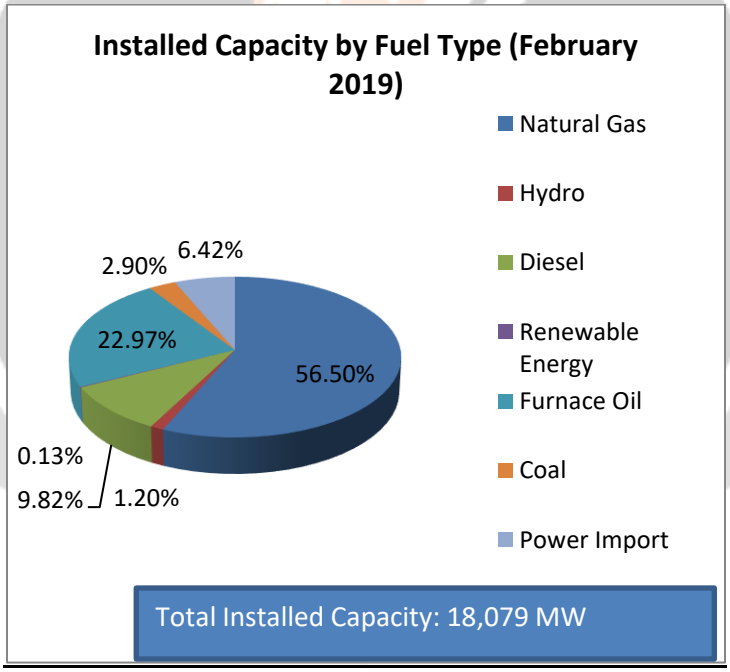

Fig. 3. Installed capacity by fuel type in Bangladesh

3. Maximum Power Generation

At present, maximum generation of electricity production is 12,893 MW in 2019 (as on May 2019) which was only 4,606 MW in 2009. The installed capacity and maximum generation since 2009-10 are illustrated in fig. 4.

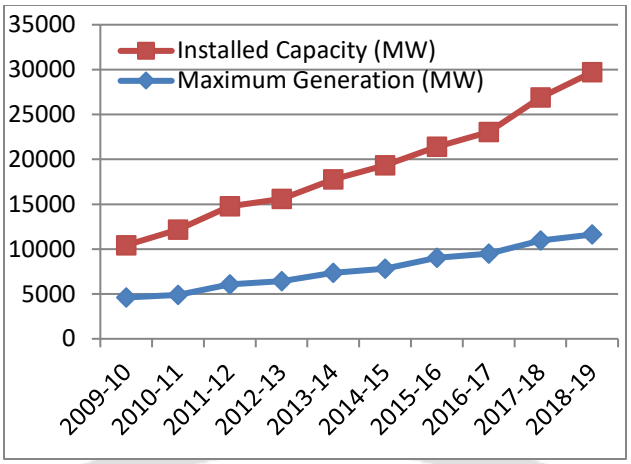

Fig. 4. Installed capacity and maximum generation

4. Renewable Energy Emphasis in Bangladesh

Bangladesh greatly relies on traditional fossil fuels for generation of electricity. Traditional fossil fuels contribute approximately 97.16% whereas 2.84% is being shared by RE as on 10 November 2019. Electricity generation mix and renewable share are shown in fig. 5. and fig.6. respectively.

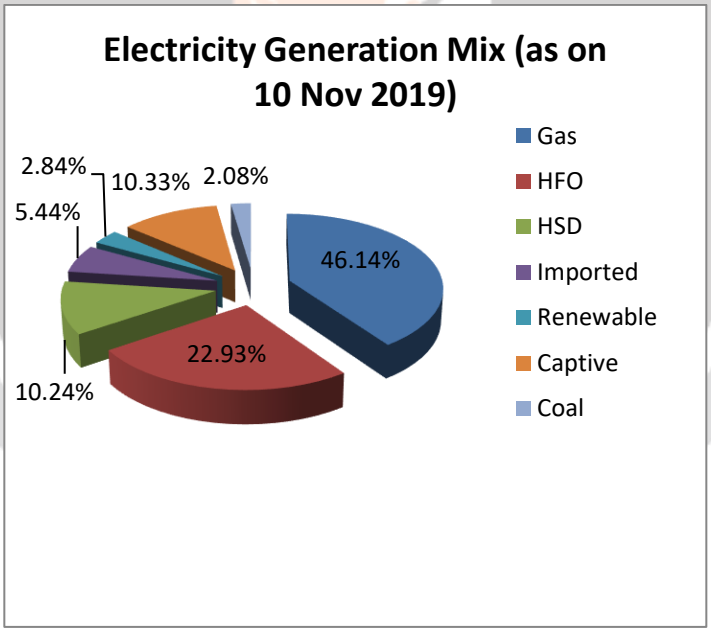

Fig. 5. Electricity generation mix in Bangladesh

It has been estimated that at the existing rate of natural gas employment and if no new natural gas field is discovered any time soon, Bangladesh is expected to run out of its natural gas reserves by 2031. Again, coal is also a key fuel for power generation. But due to different reasons, the coal mining could not be commenced effectively. Therefore, it is important for Bangladesh to quest for alternative energy to mitigate the developmental needs.

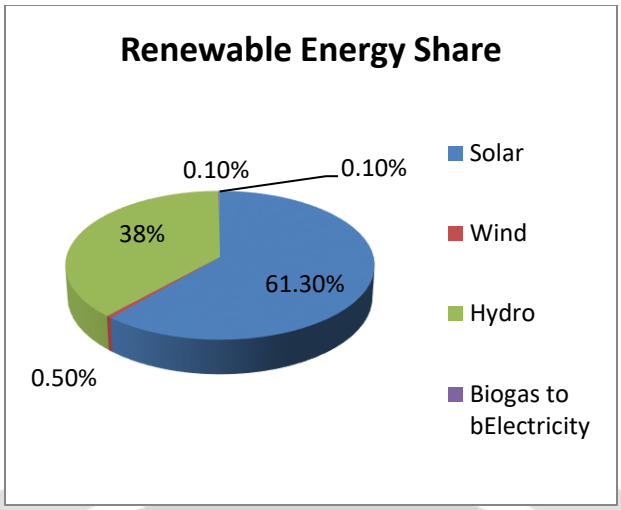

Fig. 6. Renewable energy share in Bangladesh

Total demand of electricity will be increased to 20,000 MW in Bangladesh in the year 2021. Government aims to achieve 5% and 10% of total energy production from renewable sources by 2015 and 2020 respectively and government is looking for various options to achieve it.

5. HOMER Simulation Design

The system is designed composed of PV-Photovoltaic, SW AIR X-Wind turbine, Biogas generator, H200-Battery and Diesel generator. The system architecture is given in fig. 7.

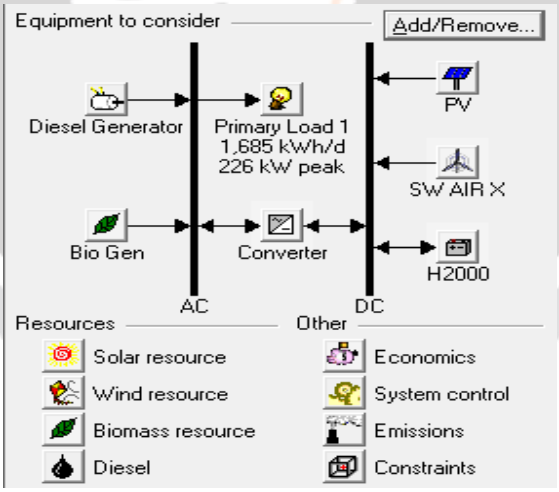

Fig. 7. System architecture in Homer (PV-Photovoltaic, SW AIR X-Wind turbine, Biogas generator, H200-Battery, and Diesel generator

6. Surveyed Area

The selected off-grid remote rural area for this study, named Swarna Dweep, lies about 4 km to the south of the Noakhali district mainland and nearly 4.5 km west and about 13.5 km north-east of Hatiya. It is an island. Study area is shown in fig. 8.

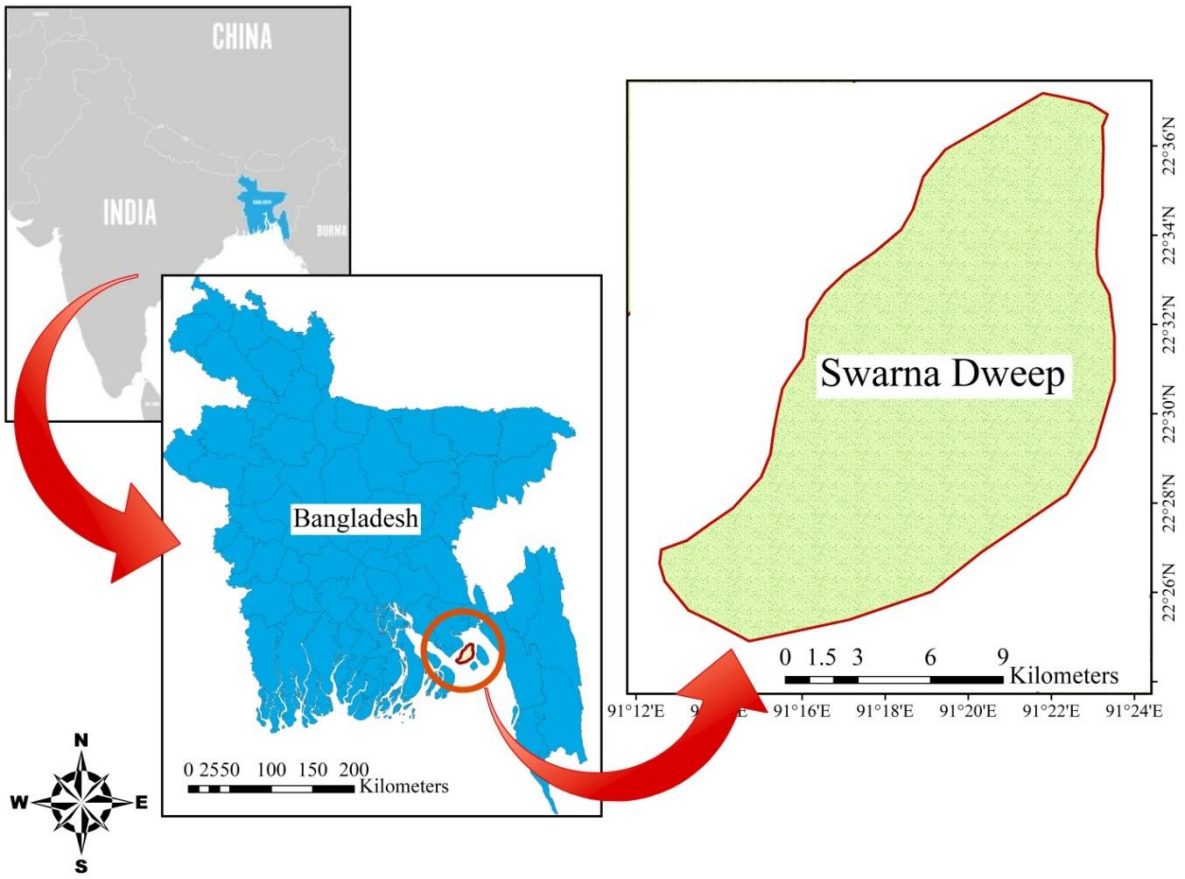

Fig. 8. Study Area Swarna Dweep island located in Bangladesh

Swarna Dweep is located within the extent between 22°37'35.5''North Latitude to 91°23'3.6''East Longitude and 22°25'12.7''North Latitude to 91°11'32.0'' East Longitude. This island is approximately 3 meter above sea level which is now 28 kilometer long and 14 kilometer wide in area (392 km^2). There is no grid electricity access of the study area as it is not economically viable so off-grid electrification is a bright option of this island.

7. Load Profile

As electrical loads light, fan, mobile charger, television and fridge are considered as main load for household requirement. The power consumption of the Swarna Dweep decreases from midnight upto 4 o'clock and electrical consumption varies from 5 o'clock to 23 hours as electrical appliances are used at different rate. The electricity consumption becomes the highest at around 1800 hours when almost all the electrical appliances are used. The average power consumption of Swarna Dweep is 1685 kWh/d. The maximum load is 226 KW which is taken into consideration for the system size. The daily load profile of study area is shown in fig.9.

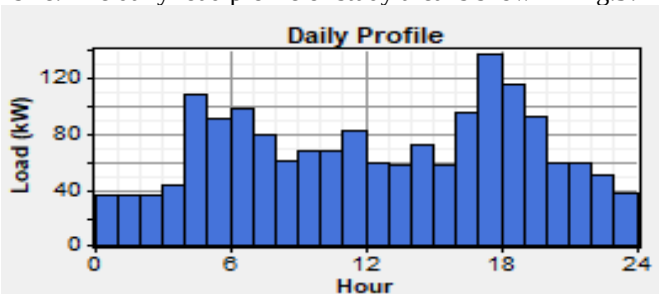

Figure 9. Daily load profile of study area Swarna Dweep island

8. Renewable Energy Potential

8.1. Solar Resources

Solar radiation data is obtained from NASA surface meteorology and solar energy database through RETScreen Expert and HOMER software. HOMER software computes clearness index automatically from the radiation values which are shown in the table 1.

Table 1. Monthly solar radiation of study area

Month	Cleanness Index	Daily Radiation ($KWh/m^2/d$) (From RETScreen Expert Software)	Daily Radiation ($KWh/m^2/d$) (From HOMER Software)
January	0.613	4.35	4.348
February	0.590	4.95	4.809
March	0.575	5.57	5.422
April	0.520	5.65	5.450
May	0.498	5.25	5.475
June	0.366	4.05	4.072
July	0.342	3.89	3.771
August	0.379	3.91	4.020
September	0.394	3.83	3.848
October	0.530	4.29	4.506
November	0.572	4.23	4.182
December	0.624	4.24	4.206
Average	**0.515**	**4.51**	**4.836**

By HOMER software, the annual average solar radiation is calculated to be 4.836 $kWh/m^2/day$ whereas 4.51 $kWh/m^2/day$ is by RETScreen Expert software and the average annual clearness index is 0.515. The maximum solar radiation was projected at (5.475 kWh/m^2) in May and the lowest was (3.771kWh/m^2) in July by HOMER software and by TETScreen Exert software maximum solar radiation was projected 5.65 kWh/m^2) in April and the lowest was (3.83 kWh/m^2) in September. Global horizontal radiation is shown in fig. 10.

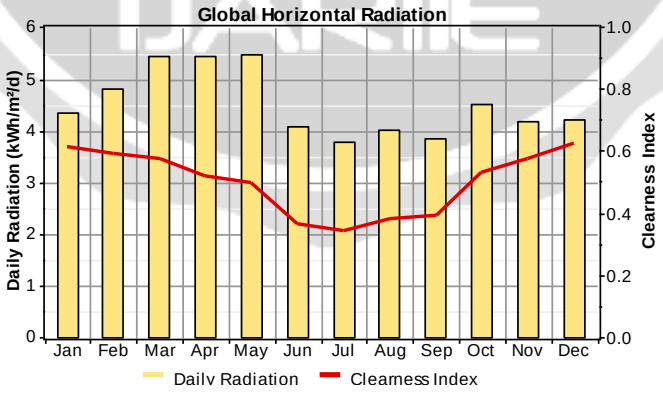

Fig. 10. Global horizontal radiation

8.2 Wind Resources

According to National Renewable Energy Laboratory (NREL), USA at height 120 meters, speed ranges from 6.5 to 7 m/sec and the annual average wind speed of Swarnadweep is 6.624 m/sec. The monthly average wind

speeds are projected in table 2. It can be also observed that from February to November the wind speed is higher than the annual average wind speed.

Table 2. Monthly wind speed

Month	NASA (10m) Wind speed (m/s) (From RETScreen Expert Software)	Measured by NREL (120 m) Wind speed (m/s)
January	2.6	6.600
February	2.5	6.590
March	3.0	6.660
April	3.8	6.670
May	4.0	6.630
June	4.4	6.670
July	4.5	6.690
August	3.9	6.670
September	3.1	6.600
October	2.3	6.590
November	2.2	6.585
December	2.3	6.595
Average	3.2	6.629

Again wind resources can be found for the same location from NASA by using RETScreen software at a height 10m for the terrain identical where it is observed that he wind speed from April to August is higher than the annual average wind speed (3.2 m/s).

8.3. Biomass Resources

There are more than 207 buffaloes, 8 cows 190 sheep and 1,200 hens, ducks and pigeons in the dairy farms. In addition to that, a large number of cattle (of which 2142 are buffalo and 1227 are cow and approximately 1065 are sheep) are grazing in the island. On average dung that can be obtained from a single healthy buffalo is 15 Kgs, a cow produces 10 kg of cow dung each day and 2 kgs by a sheep. Here the recovery rate of the dung cake for grazing catle is considered only 20%. There will be cost for collection and transportation of dung to gather in plant area of the Island. However, collection and transportation cost may be compensated by selling the slurry. Therefore, it can be said that in average 12 ton/day dung is available throughout the year.

9. System Components Assessment

The hybrid energy system of the Swarna Dweep is composed of Solar PV, wind turbine, biogas, diesel generator and power converter. The different parameters of renewable energy resources and other data need to be inserted in HOMER software to get the optimized result. The principal renewable hybrid energy source is solar PV, wind turbine and biogas to give input to HOMER.

9.1. Solar Photovoltaic

370 watt JA Solar monocrystalline PV module is considered for this system. It has few distinct advantages like better power output, exceptional low-light performance, lower temperature coefficient. The solar PV installation cost is likely to vary from (150 Tk to 300 Tk/ W). It is considered that for generation of 1W electricity from solar PV, the installation and replacement costs are likely to be Tk 100 and Tk 50/W respectively (given in Table 3). The Solar PV arrays lifetime are considered as 25-year product warranty and 25-year linear power output warranty.

Table 3. Parameters and costs considered for Solar Photovoltaic

Parameter	**Unit**	**Value (BDT)**
Initial Capital Cost	BDT/W	100
Replacement Cost	BDT/W	50

Operation and Maintenance Cost	BDT/W/Yr	50
Lifetime	Years	25
Derating Factor	Percent	90

9.2 Wind Turbine

Depending on the wind speed, generation of electricity from wind turbine varies greatly. Turbine blades are made of aluminum alloy. SW AIR X-Wind turbine is considered for wind energy. It has both on grid and off grid applications where for off grid 300V and 380V for on grid is being used. It is not only safe but also reliable than others. The cost of one unit is considered to be 2,50,000 BDT/KW while replacement costs are taken 1,50,000 BDT/KWS which is shown in table 4.

Table 4. Cost analysis for wind turbine

Parameter	Unit	Value (BDT)
Initial Capital Cost	BDT/kW	2,50,000
Replacement Cost	BDT/kW	1,50,000
Operation and Maintenance Cost	BDT/Yr/ Turbine	5000
Lifetime	Years	20

9.3 Biogas Generator

Puxin Biogas Generator is considered for this setting, Its rated power is 3 KW and it is a single phase brush motor. Its output volt is 12 V and output current is 8.3 A. Table 5 portrays the cost of Puxin biogas generator.

Table 5. Costs considered for biogas generator

Parameters	unit	value
Initial capital cost	Tk/KW	49.71
Replacement cost	Tk/KW	25
Operation and management cost	Tk/hr	7
Continue Working Time	Operating hour	Not more than 6 hours
Size of Biogas Generator	kw	3

9.4 Diesel Generator

For off grid areas, the diesel generators are normally used for electrification as its installation and operation is easier. Cost of generator is taken (7000 BDT/kW) and cost of replacement is 5000 BDT/Kw. 750 KW single unit diesel generator from Generac Industrial Power Co. Ltd. is considered for the standby power system. The size of generator is taken 1.2 times larger than the peak load demand so that it can provide power in absence of the renewable power energy. Table 6 shows the parameters and cost which are considered for diesel generator.

Table 6 Parameters and costs considered for diesel generator

Parameters	Unit	Value
capital cost	Tk/KW	7000
Replacement cost	Tk/KW	5000
Operation and management cost	Tk/hr	5
Life time	Operating hour	45000
Minimum load ratio	%	15

9.5 Battery Model

For an off grid area, battery contributes as a major cost for power systems. The battery chosen is Hoppecke 16 OPzS from the manufacturer Hoppecke. Replacement cost for battery is considered about 95% of its capital cost. The Parameters and costs considered for Hoppecke 16 OPzS storage batteries are shown in table 7.
Table 7. Parameters and costs considered for Hoppecke 16 OPzS storage batteries

Parameter	unit	Value
Nominal voltage	Volt	2
Nominal capacity	Ah(kWh)	2000(4)
Lifetime throughput	KWh	6801
Capital cost	Tk/kWh	7500
replacement	Tk/kWh	7200
Operation and management	Tk/kWh	80
Batteries per string		1 (2V bus)

9.6 Power Converter

A power converter is a device that covert current and makes an energy linkage between the AC and DC components. The power converter cost of installation and replacement are same i.e 1000 BDT/Kw each. It is ideal that the rated power of the converter should be same or greater than the peak load. Peak load be installed as power will be supplied from both from the renewable and non-renewable sources. Capital and replacement cost are same, 10,000 BDT/KW, efficiency of converter is around 90% and the lifetime of the converter will end for 20 years. Cost Analysis for Converter is given in Table 8.

Table 8: Cost analysis for converter

Parameter	Unit	Value (BDT)
Capital Cost	BDT/ kW_{rated}	10,000
Replacement Cost	BDT/ kW_{rated}	10,000
Lifetime	Years	20

10. Result

HOMER will analyze all inputs and demonstrate several possible options occurred by this system after providing the required data. It exhibits several outputs from which best option may be chosen. The combination of hybrid power system consists of components for this study is 200 kW PV-Array, 40 Wind Turbine, 40kW DG, 40 KW Biogen, 3600 Hoppecke 16 OPzS 2000 Batteries, and 650 kW Inverter. This system has considered the average solar irradiation 4.51 KW/m^2/d, average wind speed is 6.643 m/s, average bio resources is 12 ton/d and diesel cost (BDT 68/l).

11. Electricity Production

The monthly average generation of electricity of hybrid system combining of solar PV, wind, biogas and generator in KW is given in fig. 11. From June to August, the ratio of generation of electricity by solar PV, biogas and diesel is approximately same whereas in other months solar PV dominates in producing the electricity.

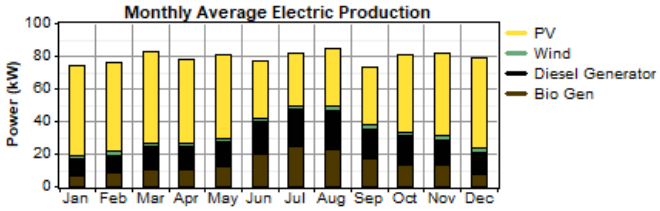

Fig-11: Monthly average electric production

The PV array contributes 59%, wind 3%, Diesel 20% and biogas 18 % of generation of electricity. Fig. 9 shows the generation of electrical from the off-grid hybrid PV-diesel-biomass-wind-battery system. The solar PV produces 409,549 kWh/year), wind 20,664 KWh/year, Diesel generator 141,152 KWh/year, Biogas generator 124,320 KWh/year which is given in Table 9.

Table 9: Generation of electricity for proposed solar-wind hybrid energy system

Production	kWh/Yr	%
PV Array	409,549	59
Wind Turbines	20,664	3
Diesel Generator	141,152	20
Biogas Generator	124,320	18
Total	695,686	100

Excess production of electricity depends on high value of solar radiation, accelerated wind speed and plenty of biomass. Again, due to inclement weather conditions, generation of electricity will be interrupted. It is assumed that hybrid system may generate excessive electricity which may be stored into battery or may be used during bad weather condition. Thereby, round the year, continuous electricity supply is possible.

12. Simulation Results

Fig. 14. shows the cash flow summary for the optimal system. The initial cost of solar PV is approximately 32% wind is 14.6%. Whereas biogas is less than 1% of the system's total cost. The system fixed capital costs include various civil constructions, labor, logistics wages, required licenses, administration and government approvals and other miscellaneous costs.

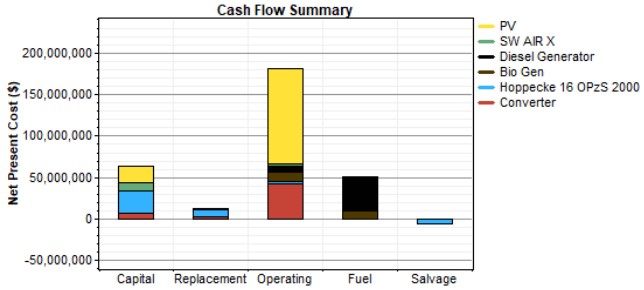

Fig. 12: Cash Flow Summary

13. **Optimization Results**

Based on the inputs, HOMER executes both simulations and optimization. All renewable energy resources along with diesel generator and battery are the input for HOMER. After running the HOMER, to options were obtained. In first option, all renewable resources are accounted to generate electricity. The system capital cost is 62,901,200 taka, replacement cost is 12,120,463, operation & maintenance is 180,852,880 and fuel cost is 49,979,888 taka. For option 2, all renewable resources less wind are accounted to generate electricity. The system capital cost is 58,700,896 taka, replacement cost is 10,179.287, operation & maintenance is 203,976.944 and fuel cost is 33,649,688 taka. In the simulation, the NPC is calculated for option 1 is 299, 121,664 and option 2

300,831,168. For option 1 COE is 38,071 tk/Kwh and regeneration fraction is 0.8 and for option 2, COE is 38,279 tk/Kwh and regeneration fraction is 0.88. Therefore, option 1 bears lesser cost comparing to option 2.

14. Sensitivity Analysis

For sensitivity analysis, the accurate economic inputs play a significant role to get the net present cost (NPC), cost of electricity (COE) etc. The total NPC, capital cost and COE for this hybrid system are ($299,121,504 BDT, 62,901,200 BDT and Tk 38.071/kWh), respectively. Now, if the load demand increases, then it will equally affect the NPC, CoE operational and maintenance cost.

15. Conclusions

It is expected the with more than two renewable resources, the hybrid system will operate well. But system reliability cannot be confirmed due to unpredictable behavior of the nature. It is assumed that solar irradiation and wind speed likely to be low in winter. The off grid area like Swarana Dweep's load demand will meet from the hybrid power system solar PV, wind, biogas combination with a cost Tk 38.071/kWh. If any of the renewable resources are not available, other resources will able to meet the required demand. If there is less number of consumers, its prices are likely to be more and clients may find this project less attractive one.

Authors Contribution

First author has outlined and articulated the total paper and second author has given necessary corrections and comments to improve the paper.

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References

[1] https://en.wikipedia.org/wiki/Electricity_sector_in_Bangladesh, accessed on 10 October 2019.
[2] Hossain M. Power generation plan to fulfill the government's vision 2041: Role of renewable energy. *Looking to the Future, 2nd Anniversary 2016 Journal, SREDA*, pp 08.
[3] http://www.sreda.gov.bd/index.php/site/re_present_status , accessed on 10 October 2019.
[4] Rahman T. UNDP supports climate mitigation through renewable energy: Present status & roadmap of Bangladesh. Available on: https://www.slideshare.net/trsumon/renewable-energy-status-and-roadmap-of-bangladesh-and-support-of-undpgef, accessed on 17 October 2019.
[5] Abedin J. Renewable Energy: Where Do We Stand? The Daily Sun, 27 July, 2018, Available on: https://www.daily-sun.com/printversion/details/325047/2018/07/27/Renewable-Energy:-Where-Do-We-Stand, accessed on 15 October 2019.
[6] Gofran M. A. Status of biogas technology in Bangladesh. The Daily Star, 05 September 2007. Available at: https://www.thedailystar.net/news-detail-2631, accessed on 17 October 2019.