Hybrid Power Optimization in St.Martin Island With Smart Grid Modeling

Hasibul Jamil, Swarup Chakraborty, Md. Mamunur Rahman

Abstract— Modern era is looking at the sustainable energy for a permanent solution to the future power demand all over the world whereas the countries of the third world like Bangladesh is still failure to meet the present basic power demand. St.Martin Island is one of those places which are still out of national grid in Bangladesh. More than 8000 inhabitants belonging to about 1200 families are living there but only 26.4% of them are connected to electricity. Moreover grid connected electric system is quite impossible even in future because of costs and geographic location. Present electricity demand is partially fulfilled by the stand-alone diesel generators only for four hours per day which are also badly affecting the ecological balance and environment with a large amount of CO_2 emission. This paper has been documented as a small attempt to give a solution of the power crisis of St.Martin Island with optimizing hybrid power generation scheme concentrating on sustainable energy. Using HOMER analysis, an optimum configuration is established among a set of systems to supply electricity to about 1400 families, 150 shops, 100 hotels and various organizations. The load calculation for the whole island has an outcome of a demand of energy about 4000KWh per day with a peak load of 504KW. This system which is the best one chosen from the output results from HOMER, incorporates a combination of 600KW decentralized Solar PV, 3 wind turbines of 1.8KW each, 2000 batteries of 800Ah each, 300KW biomass generator and 15KW diesel generators to fulfill the whole power demand of St.Martin Island. This hybrid power generation system concentrating on renewable energy may be an effective solution to the present power demand of St.Martin Island without hampering the ecology and environment. Besides, it may be an ideal example of a renewable hub because of its high renewable fraction.

Index Terms— Biogass, Biomass, Diesel, Hybrid, Solar PV, Renwabble Energy, Wind.

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1 Introduction

Energy is the main source of all kind of development for a country. A well-settled and developed country can be raised based only on their efficiency in energy usage. It is really difficult to imagine our lives without electric energy in present days. Most of the things are run by electricity in our everyday life such as lights, appliances, cooling and heating for home and business. Each and every sphere of our life is now fully dependent on it but none thinks it deeply as long as electricity is available. The minutes an outage happens in the power system, the importance of electricity is realized. However, still lots of people around the world do not have the access to reliable electric energy. There are 1456 million people in the world without electricity. Among them, 1453 million people from the developing countries like Bangladesh, India, Sri Lanka, Pakistan etc. World electrification rate is 78.2% (urban 93.4% and rural 63.2%) [1].

Bangladesh is a developing country where majority of people live in the rural areas which are about 80% of total population [2]. A large amount of people living in rural and remote areas are deprived of grid connected reliable electric energy. The 60% of the total population is connected to the grid electricity [3]. As Bangladesh is no more an underdeveloped country and becoming industrialized day by day, its economy is growing and electricity demand is going to be increased at a faster rate. However, the demand of electricity is increasing annually by 10% [3]. Therefore it is significant challenge for the government to respond to the increasing demand and also provide accessibility to electricity to the rest of population who do not have access to the electricity.

The situation is worst and more severe in the isolated islands like: St.Martin Island, Kutubdia, Hatia etc. which are still deprived of grid connected reliable electrical energy. Grid connected electricity may not be possible even in future because of costs and geographic location. Most of the inhabitants of these islands are leading their lives without electricity. They are totally out of the light of the modern world and their development and prosperity is going to be endangered day by day. These vast coastal areas have a lot of possibilities of industrialization and development but only hindrance against their prosperity is the need of electricity. St.Martin Island is one of these islands, still deprived of reliable electricity and the inhabitants can't even meet their basic needs like: education, medical facilities and still they are leading a very poor standard life only due to the power crisis [4]. They are fully detached from the modern world only for the lack of power. Tourism is also badly affected by the shortage of power. So, meeting the energy crisis of St.Martin's island is a crying need. The primary source of energy in these communities is diesel, kerosene and wood. Extending the power grid connection is very expensive and unrealistic because of long sea-way and lack of proper technology. So, Off-grid electricity is the only hope for this island. St.Martin Island is very rich in renewable energy sources such as Solar, Wind and Biomass. In this work, an Off-grid hybrid power system with different resources such as Photovoltaic, Wind turbine, Diesel generator, Biomass and

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Battery storage has been designed and optimized for the cost effectiveness by using HOMER for making the region self-sufficient in power sector associating Smart grid Power system [5].

2 LITERAUE REVIEW

Bangladesh is suffering from an acute energy crisis. Natural Gas is the main source of commercial energy. The real demand for electricity could not be met due to the shortage of available generation capacity. A good number of generation units have become very old and have been operating at a much reduced capacity [3]. As a result, their reliability and productivity are also poor. Power generation system of Bangladesh is completely dependent on non-renewable energy sources which are going to be end very soon. Therefore it is must to figure out the alternative renewable energy sources where they are available in our country. Almost every region of Bangladesh is full of renewable energy sources and the existing power systems on these regions can be replaced by Hybrid power generation system concentrating on renewable energy sources.

Solar energy and wind energy have been deemed clean, inexhaustible, unlimited, and environmental friendly. Such characteristics have attracted the energy sector to use renewable energy sources on a larger scale. However, all renewable energy sources have drawbacks. Wind and solar sources is dependent on unpredictable factors such as weather and climatic condition. The prospect of Biomass energy is also vast in Bangladesh. But it has also some adverse effects on environment and ecology if the process of harnessing power is not environment friendly and production often depends on the availability of biomass energy sources. Due to both sources complementary nature, some of these problems can be overcome the weaknesses of one with the strengths of the other. This brings us to the hybrid solar-wind-biomass-diesel power plant concept. Hybrid power plant is a concept of co-ordination of multi fuel power generation plants. Hybrid energy stations have proven to be advantageous for decreasing the depletion rate of fossil fuel, as well as supplying energy to remote rural areas, without harming the environment.

Hybrid renewable energy systems (HRES) are becoming popular for remote area power generation applications due to advances in renewable energy technologies and subsequent rise in prices of petroleum products. Hybrid systems, like the name implies, combine two or more modes of electricity generation together, usually using renewable technologies such as solar photovoltaic (PV), wind turbines & biogas generators. Hybrid systems provide a high level of energy security through the mix of generation methods and often will incorporate a storage system (battery, fuel cell) or small fossil fueled like Diesel generator to ensure maximum supply reliability and security.

Research on hybrid power system combining renewable and fossil derived electricity started 25 years ago, but few have written papers about system implementation and experimental data collection. There are many papers that optimize hybrid system cost and a few noteworthy papers are mentioned here. J.K. Maherchandani examined the economic feasibility of converting stationary diesel plants in rural India into Biomass / wind / Photovoltaic (PV) plants and found that conversions were economically favorable for smaller diesel-based system. The cost savings of converting an electric generation from diesel into PV / Wind / Diesel [6].

A.K.M. Sadrul Islam et al. examined and went through a feasibility analysis on hybrid power generation model incorporating solar, wind and diesel generators for St.Martin Island and they proved that hybrid off-grid power generation model can be a feasible solution of present power crisis of St.Martin Island. But they incorporated a huge no. of wind turbines which may not be feasible with the most variable and low wind speed available in St.Martin Island [7].

Md. M. Biswas et al. researched on the prospects of renewable energy resources and their possible power generation capacity in Bangladesh. They concluded that Solar and biomass energy has very good prospects in near future in Bangladesh and especially the coastal areas like: St.Martin Island, Kutubdia, Maheshkhali etc. are perfect project sites to be undertaken on renewable projects. They noted that there are many possible ways in which goals of meeting energy demand can be carried out in Bangladesh; through combinations of different renewables technologies, grid based generation and micro-renewables and energy efficiency [8].

Smruti Ranjan Pradhan has examined with Hybrid system based on biomass and PV technology for an off-grid remote region of India. They concluded that, these hybrid systems along with back-up diesel generators are the most feasible solutions among all kind of power generation schemes for those kind of remote areas [8].

All the researchers have experimented with the probable small scale load calculation. They didn't experiment with the total load of the respective area rather they treated with a few families and shops taking under consideration

3 CASE STUDY

At present most of the energy generated in Bangladesh is from fossil fuel. St. Martins is one of the major off Shore Island in Bangladesh which is almost 18 km away from the main land: In between 20° 34' - 20° 39'N and 92° 18'- 92°[4]. There are about 1200 families in the St. Martins Island with a population of about 8000. Only 24% of the inhabitant of the St. Martins Island is using the electricity [10]. For the electrification of St. Martins Island Bangladesh Power Development Board (BPDB) has set up a large Diesel powered generator in 1985. At that time there were 300 families. It was the first off grid project undertaken by BPDB. That generator had the rating of about 120KVA and 2KW which supplied power in three parts of the island mainly. This generator was completely damaged in cyclone in 1991. Still now there are few poles and towers with overhead transmission lines in the island [11]. At present the electricity demand in the island is meet from some small scale diesel powered generator. The available generator is given in the Table 01.

TABLE 1
AVAILABLE GENEROTOR'S STATUS IN ST. MARTIN

Generator owner	Gen-erator size	Generator No.	Generator rating
Blue Marine Resort	Small	1	5 kW
	Large	2	15 kW, 220 V, 68.2amps, 1500rpm
Hotel Obokash	Small	1	10 kW, 220 V, 45.6 amps., 1500 rpm
	Large	2	22 kVA, 15 kW, 220 V, 68.2 amps, 1500rpm
Mahbub Alam;	Small	1	15 kVA
	Large	2	30kVA,p.f.0.8,50Hz,400V,43A
Abdur Rahman	Small	1	7.5kW
Small Hotels	Small	70	1-3kW

For Blue Marine Resort fuel consumption is 3.5 liter diesel per hour in full load. The total connected load is 19.4kW [12]. For hotel Obokash fuel consumption is 3 liter diesel per hour in full load. The total connected load is 24kW [13].

Another project was undertaken by BPDB in St. Martins Island to encourage people for using renewable energy but the outcome of the project is not seen yet. In this project two acres of land is used for commercial use and for the electrification of cottages, 7kW solar panel systems were installed [11].

A planned, stable and optimized hybrid system can eradicate the dearth of electricity

4 LOAD ANALYSIS

From the previous section it is seen that the geographical position of St. Martins Island is such that connecting this territory with main grid will increase the cost of operation and maintenance to an impractical level. Instead of grid extension, installing a decentralized micro grid will be much more cost efficient and environment friendly.

To install this type of system several important parameters need to be considered. They are exorbitancy of resource, Low carbon footprint, Low emission, Efficiency, Low price.

The three most important criteria of load analysis are energy consumer, the time of the year, the time of the day.As the economic condition varies from people to people, and their lifestyle varies accordingly. When the financial condition of the people improves their energy consumption increases. The load demand varies of different times in a day. Again in different times of the year the peak load as well as the base load vary significantly.

TABLE 2
FINANCIAL CONDITION OF THE DWELLERS OF ST. MARTIN

Types of family	No. of Family	Connected load	
Very solvent	200	Lights	4
		Fans	3
		TV	1
		Fridge	1
		Socket	2
		Water pump	1
Solvent	800	Lights	2
		Fans	2
		Socket	2
Poor	400	Lights	1
		Fans	1
		Socket	1

If we classify the peoples of the St. Martins according to their financial condition then they can be categorized into three major categories. They are very solvent, solvent and poor [14]. Their number and their appliance for load analysis are given in the above table.

The hourly load profile is calculated considering all loads as AC loads and random variability is considered by 15% day to day and 20% time step to time step variability.

The load variation in different times of the year is considered. The four main seasons of Bangladesh are taken into consideration. The seasons are December, January, February i.e. winter season, March, April and May i.e. summer season, June July and August i.e. rainy season and September, October and November i.e. autumn season. The following Fig.1 shows the hourly load curve for the four categories previously explained. Peak load is considered as 295 KW but the base load is considered as 28.35 KW. Considering the safety aspects, random variability the daily load profile is generated. The daily load profile is shown in the following Fig. 2.

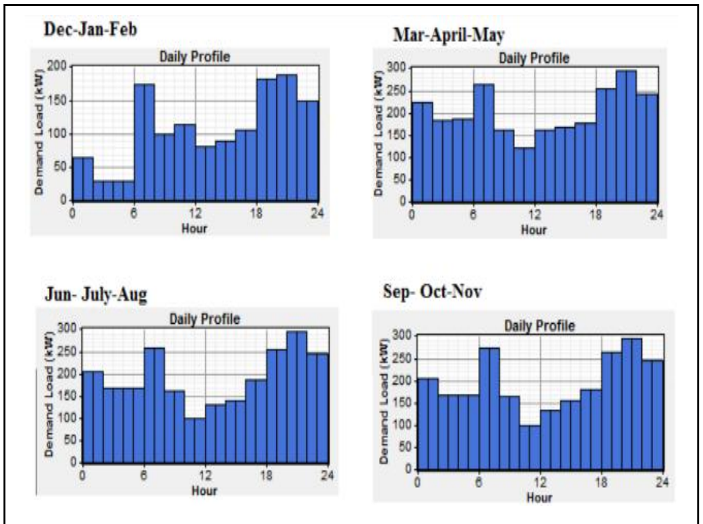

Fig. 1. Load curve of different seasons of the year

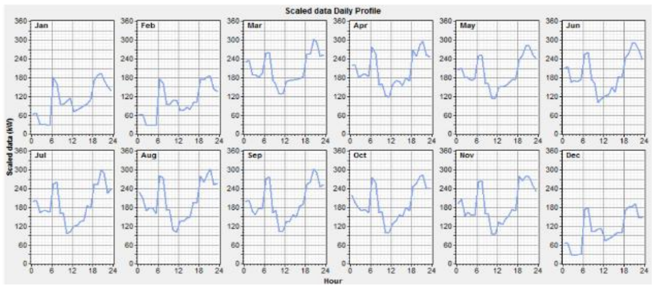

Fig. 2. Daily load profile (KW vs. Hour)

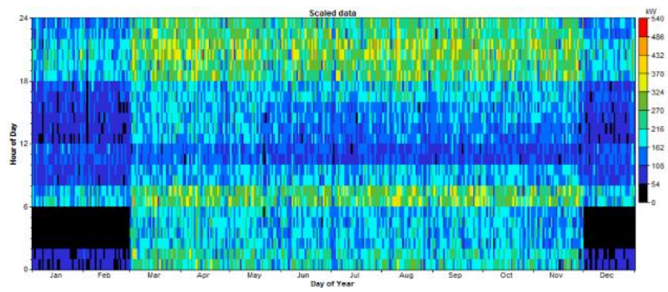

Fig. 3. Data Map (DMap) of estimated load throughout the year

Variations of load with respect to every hour in each day of the year as well as load duration curve are shown in the Fig. 3.

5 Resouse Assesment

Since St. Martins is a tropical island, various potential renewable energy source can be considered for harvesting energy. The main renewable resources are solar, wind and biomass. But it is also true that being a small island it is almost impossible to meet the energy demand of this huge population with only renewable resource. The available renewable resources are described in the following subsections.

5.1 Solar Resorce

As St. Martin Island is away from the main land of the country, less pollution is faced here and the clearness factor is high. Though there is no solar irradiation data is available for the St. Martins Island, the approximate average solar irradiation data can be obtained from the NASA's website by giving the central coordinate of the island. From this average data by

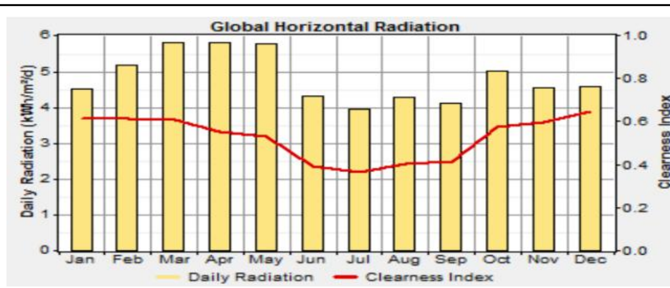

Fig. 4. Global horizontal radiation in St. Martins Island

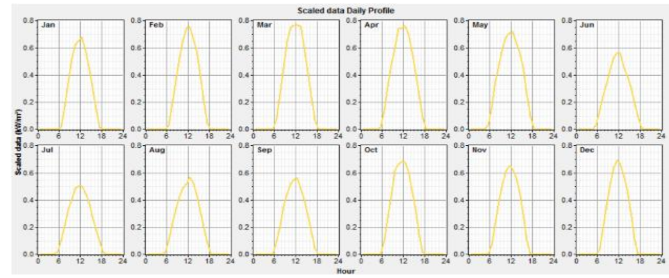

Fig. 5. Hourly profile of Irradiation of Solar energy

using Graham Algorithm the hourly data is generated in HOMER software [15]. The following graph represents the solar irradiation information of the whole year.

It can be seen from the graph that the solar irradiation is high in February to April i.e. in dry season. The average clearness factor is about 0.513 and average irradiation daily is almost 4. 82 KWh/m2/d. The hourly solar irradiation data is generated from the Graham Algorithm is given in the following Fig. 5.

Irradiation is considerably poor from June to August i.e. rainy season due to the presence of cloud in extraterrestrial surface. But the above data is enough to take decision that the installation of solar panel to harness energy from the sun will be a potential source of energy.

5.2 Wind Resource

There is no recent data on available wind resource in St. Martins Island. A survey on wind resource is undertaken by the Bangladesh Scientific Research Institute from year 1999 to 2001. This survey was not continuous. They took data only for a few hours of the day. The average monthly wind speed data can also be achieved from the NASA's website [15]. The average monthly wind speed data is shown in the Fig. 6.

The generation of the hourly wind speed data needs three major factors. They are Weibull value, auto correlation factor and the diurnal pattern strength. The Weibull factor i.e. the value of k is used to measure the distribution of wind speed and it is taken as 2 for this analysis. The autocorrelation factor is used to determine the randomness of the wind and the value of this factor is 0.78. The diurnal pattern strength measures the strength of wind in different times of the day and the value taken for this case is 0.3. Only 3m/s wind is needed for the proper operation of the wind turbine. The wind turbines power curve is given in the Fig. 7.

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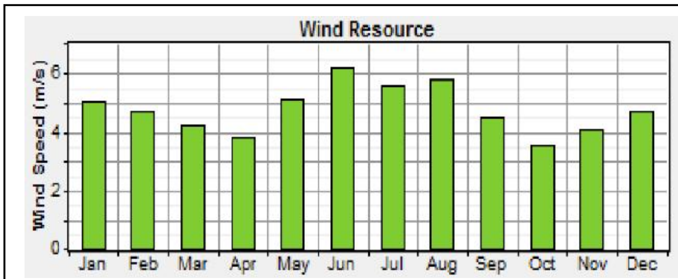

Fig. 6. Average Wind Speed (m/s)

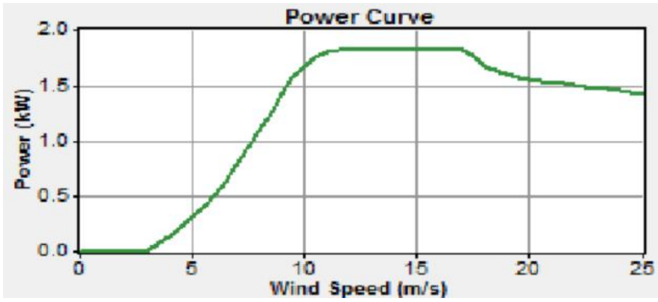

Fig. 7. Power Curve of SW Skystream 3.7 Wind Turbine

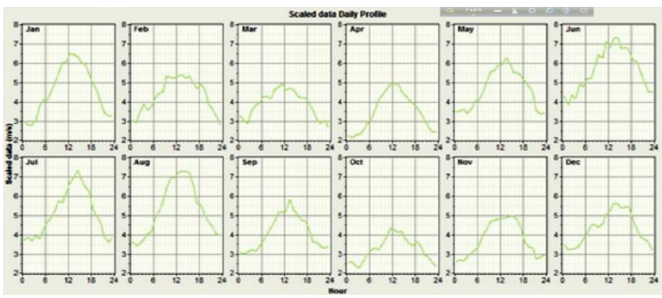

Fig. 8. Hourly wind speed profile throughout the year

Average wind speed varies from 2m/s to 7 m/s in the months of June, July and August. The hourly wind speed profile throughout the year is shown in the Fig. 8.

5.3 Biomass Resource

Since St. Martins is a small island its own biomass resource will not be able to cover all the energy demand of the island. But there is number of dairy farm and the poultry farm in the nearby territory of St. Martins Island. The areas are Teknaf, Ukhia, and Shahporir Dwip. If the biomass resource of these territory can be acquired then enough energy can be harnessed from these resources. There are total no. of domestic animal (large) = 152982 and total available waste = 1550ton /day. It should also be taken into account that all the biomass resource cannot be collected for various unavoidable circumstances. Considering these, only 39% of the total biomass resources is taken into account. Even after this consideration, the usable biomass resource will be 400 ton/day.Also, for this analysis the gasification ratio is considered as 0.35 and the LHV of biogas is considered as 5.5MJ/kg. The biomass resource in Teknaf region is given in the Table 03 while the available layer poultry farm in Ukhia is given in the Table 04.

TABLE 3
THE BIOMASS RESOURCE IN TEKNAF

Poultry and Layer Farm	
No. of Boiler poultry farm	35
No of total boiler chicken	35000
No. of total layer hens (there is 3 layer farm)	3000
No. of total Chickens	38000
Dairy Farm	
No.of total dairy farm	29(recorded)
No. of total cattle	49000
**The main crops of Teknaf are rice, betel leaves, and Betel nuts.	

TABLE 4
THE BIOMASS RESOURCE IN UKHIA

Name of poultry farms	No. of farms	No. of chickens per farm	Total no. of chicken
Beauty	53	1000	53000
Jannat	60	1000	60000
Sohel	9	1000	9000
Moriccha	50	1000	50000
Dairy Farm			
No.of total dairy farm		8 (recorded)	
No. of total cattle		53,982 (recorded)	

6 ANALYSIS

In Bangladesh, the islands such as Sandwip, Kutubdia, Maheshkhali, St. Martin and other rural areas are not suitable for grid connected system. If the extension of national grid through the high voltage transmission line is done for these areas, risk of electricity theft, high price of connection of remote areas and limited willingness to pay for electricity may be encountered. On the other hand, power transmission losses are occurred due to long transmission line.

For these off-grid areas of Bangladesh, the stand-alone PV or wind power system may not be cost effective. So combination of different available power sources are used which is termed as hybrid power system. A hybrid power system uses renewable energy as a primary source and a generator set (most of the time diesel fed but potentially with gasoline and LPG) as a backup resource.

For the acquired data, several models are simulated using HOMER software. The simulations can be characterized into two major categories. They are 1. Standalone systems and 2. Hybrid systems. In the next two subsections this two categories are described.

6.1 Stand Alone System

The main Standalone systems are standalone diesel generator system, standalone solar PV system, standalone biogas generator system.

6.1.1 Stand Alone Diesel Generator

In this model it is assumed that one large diesel generator will supply the total load of the territory all the time. The modeled system generator has the hour of operation about 8759hr/year, operational life will be 1.71 year, and the capacity factor is 34.9%, the generation as well as marginal generation cost as 3085Tk/hr. and 24.8 Tk/KWhr respectively. If the power is supplied without any interruption then 723636 liters of diesel is required where 0.48 liters of diesel is required to produce unit power. The mean electrical efficiency is obtained as 21.5%. The following DMap shows the diesel generator

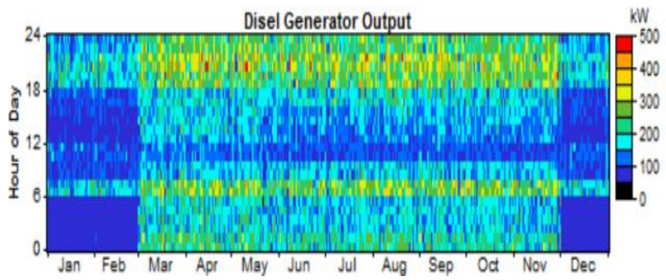

Fig. 9. DMap showing the variability of diesel generator output throughout the year

TABLE 5
EMISSION OF THE STAND ALONE SYSTEM

Pollutant	Emissions (kg/yr)
Carbon dioxide	1905571
Carbon monoxide	4704
Unburned hydrocarbons	521
Particulate matter	355
Sulfur dioxide	3827
Nitrogen oxides	41971

output throughout the year.

The energy cost per unit is 42.8 Tk which is almost nine times more than the conventional energy. In section 4, it was described that the two major parameters are low emission and low carbon footprint. The Table 5 shows the emission of the standalone system. The CO_2 emission is more than 1.9 million kg and CO emission is more than the 4500 kg per year which is enough for the disruption of the ecological balance of the St. Martins Island. Considering the cost per unit energy as well as high carbon footprint, this model will be uneconomical.

6.1.2 Stand Alone Solar PV with Backup Batteries

In this system the energy is mostly harnessed from the PV module. The energy is stored in the battery and the battery is charged from the rectifier output. Power is delivered from the battery to the grid using inverter. The architecture of this system is given in the Fig. 10.

For the implementation of this model large amount of land area is required. For this model PV array of 2500kW, 1200 pcs of Hoppecke 8 OPzS 800 battery of 2V each, inverter of 500kW, rectifier of 475kW is proposed. The monthly average Electrical production is shown in the Fig. 11.

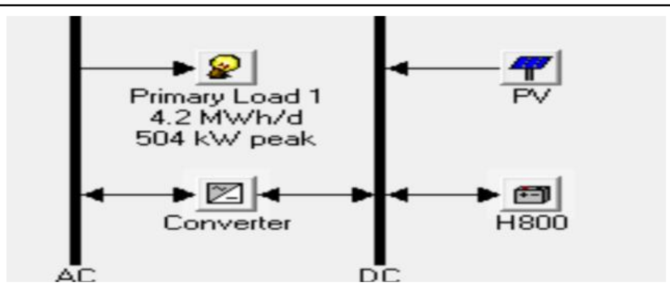

Fig. 10. System configuration of standalone solar PV system

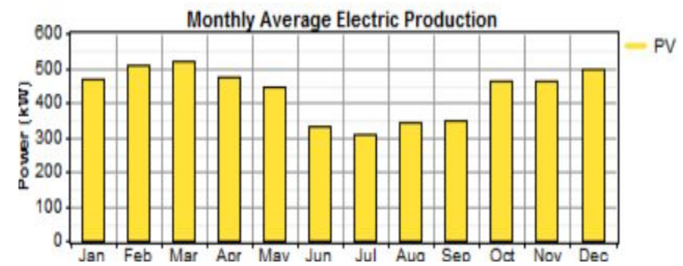

Fig. 11. Monthly average electricity production throughout the year using Solar PV.

TABLE 6
PV PARAMETERS

Variable	Values	Unit
Rated Capacity	2500	kW
Mean Output	430	kW
Mean Output	10327	kWh/d
Capacity factor	17.2	%
Total Production	3769387	kWh/yr
Minimum Output	0.00	kW
Maximum Output	2473	kW
PV penetration	248	%
Hours of operation	4463	hr/yr
Levelized cost	4.43	Tk./kWh

In this model PV, Battery and Inverter is analyzed separately.

For the simulation of the optimized standalone solar PV the parameters are considered in Table 6.

The solar PV output variability is shown in the Fig. 12.

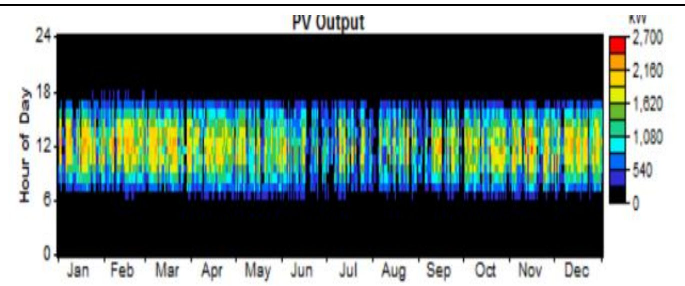

Fig. 12. Variability of PV output throughout the year for standalone solar PV system

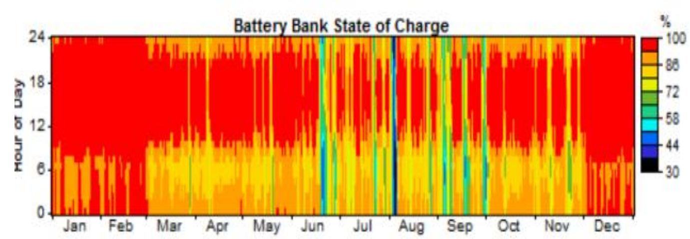

Fig. 13. DMap of state of charges of the batteries for various hours in a day for standalone solar PV

Since the nominal voltage of the battery is only 2V and the current rating is comparatively low so the several batteries are used in series parallel combination. There are 6000 strings in parallel where each string contains 2 batteries i.e. there are 12000 batteries are used for the modeling of this systems. The state of charge (SOC) of the batteries for different times of the day throughout the year is shown in the Fig. 13.

The inverter for the supply of energy to the bus is required. 34.7% capacity factor with the hours of operation of 8,757hrs/yr are considered for the optimization. The total loss is about 168,876 kWh/yr.

6.1.2 Stand Alone Biogass Generator

In this model it is assumed that only biogas plant will be used for harvesting energy. The Architecture of this model is given in the Fig. 14 while the parameters which have been considered for the operation of the biogas plant are in Table 7.

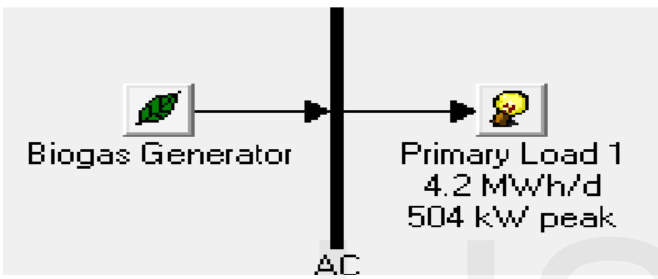

Fig. 14. System Configuration of Stand-alone Diesel Generator

TABLE 7
PARAMETERS OF BIOGASS PLANT

Variable	Value	Unit
Nominal capacity	19200	kWh
Usable nominal capacity	13440	kWh
Autonomy	77.4	hr.
Lifetime throughput	32904000	kWh
Battery wear cost	3.933	Tk./kWh
Average Energy cost	0.00	Tk./kWh
Energy In	1202555	kWh/yr
Energy Out	1035631	kWh/yr
Storage depletion	1290	kWh/yr
Losses	165633	kWh/yr
Annual Throughput	1116751	kWh/yr
Expected life	20.0	Years

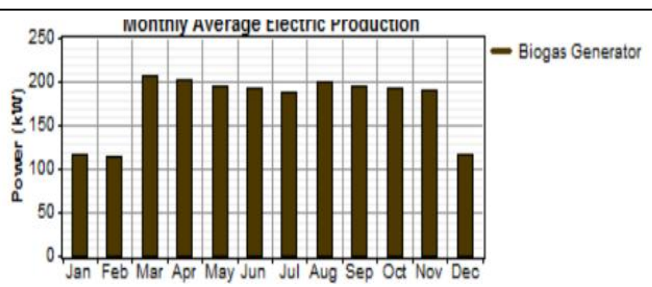

Fig. 15. Monthly average electricity production throughout the year using Biogas generator.

TABLE 8
EMISSION ANALYSIS

Pollutant	Emissions (kg/yr)
Carbon dioxide	937
Carbon monoxide	35.2
Unburned hydrocarbons	3.9
Particulate matter	2.66
Sulfur dioxide	0
Nitrogen oxides	314

By considering the above mentioned parameter and the biomass input described in the above section, we can find the monthly average electrical production all the year round as in Fig. 15 and the emission analysis is shown in the Table 8.

6.2 Hybrid Systems

Among the three basic renewable source and the diesel source two most promising hybrid models are analyzed. Although different models can be analyzed for different combination the cost effectiveness, efficiency and emission are the most important parameters that are analyzed in this section.

6.2.1 Solar PV and diesel hybrid system

In this system the modules used for developing model are PV array diesel generator, battery inverter and rectifier. The architecture of the configured system is given in the Fig. 16.

Here the PV module of 1500kW, diesel generator of 300kW, 5000 Hoppecke 8 OPzS 800 battery, inverter and rectifier are of 500abd 475 kW respectively. This hybrid configuration incorporating solar PV and Diesel generators which produce 2.48 GWh electrical energy per year where 91% of the total comes from PV array and rest 9% comes from diesel generators. In the Table 9, the production and the fraction of the solar PV and the diesel generator respectively shown.

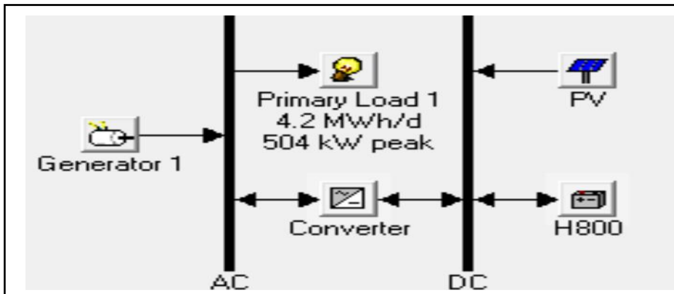

Fig. 16. System Configuration of Solar-Diesel Hybrid

TABLE 9
PRODUCTION DATA

Component	Production (kWh/yr)	Fraction
PV array	2,261,632	91%
Generator 1	226,917	9%
Total	2,488,549	100%

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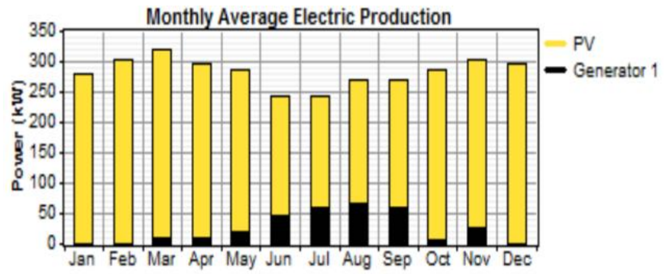

Fig. 17. Monthly Average Electrical Production of Solar-Diesel Hybrid

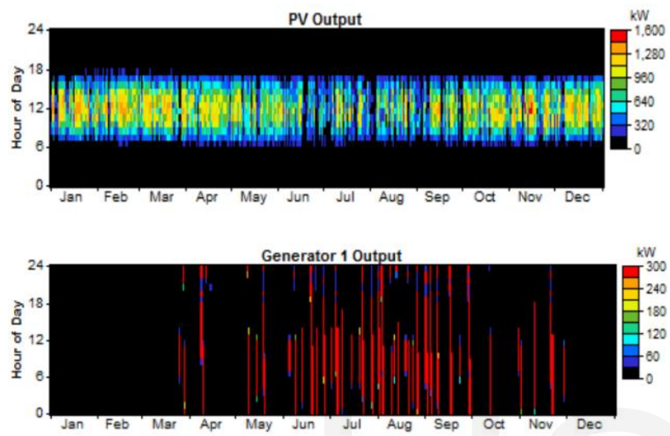

Fig. 18. DMap of PV & Diesel generator operation in the Solar-Diesel hybrid system

Monthly average electrical production from Solar PV and Diesel Generators individually has been shown in the Fig.17.

The variability of PV operation and Diesel Generator operations throughout the year shown in the Fig. 18.

The batteries is used for the storage of the energy in the day from the solar PV. In this model there are 5000 batteries. As each battery voltage is about 2V so the bus voltage is about 4V. The state of charge of the batteries in different times of the batteries is shown in the Fig. 19.

For the time of need the stored energy is delivered to the load. 500kW inverter and 475 kW are required for supplying to ac load and for battery charging respectively. It is assumed that the capacity factor, hours of operation of inverter and rectifier are 31.5%, 1.8%, 8047 hrs. /yr and 702 hrs. /yr respectively. The losses for inverter and converter are 153,296kWh/yr, 12,990 kWh/yr. Though the yearly CO2 emission is more than 2.3 million kg and CO emission is more than 570kg per year, this model is comparatively more environment friendly. The Table 10 shows the emission analysis:

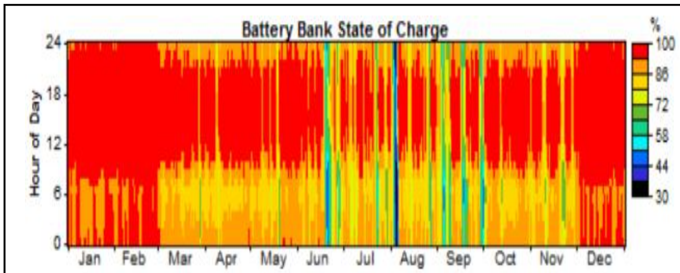

Fig. 19. DMap of State of charges of the batteries in a day Solar-Diesel hybrid system

TABLE 10
EMISSION ANALYSIS

Pollutant	Emissions (kg/yr)
Carbon dioxide	230,726
Carbon monoxide	570
Unburned hydrocarbons	63.1
Particulate matter	42.9
Sulfur dioxide	463
Nitrogen oxides	5082

6.2.2. Solar PV - Wind - Biomass - Diesel Hybrid Systems

This hybrid system has been incorporated with solar PV, wind turbine, biogas generator as the primary sources and diesel generator as tertiary or back-up sources. In this model solar PV, 3 pcs SW Skystream 3.7 wind turbine, 15 kW diesel generator, biogas generator of 300 kW, 2,000 Hoppecke 8 OPzS 800 batteries, 300 kW inverter, 285 kW rectifier is used. The architecture of this system is shown in the Fig. 20.

This hybrid configuration incorporating Solar PV, Wind, Biomass, Diesel generators produces 1.85 GWh electrical energy per year where about 49% power can be harnessed by using Solar PV and about 50% power can be earned by using Biogas generators. Though it is possible to meet the electrical demand of the island using these renewable energy source, a 15 KW diesel generator is also required as the back-up source in case of peak demand. The Table 11 clarifies the fact.

This hybrid configuration is 99.3% renewable and capacity shortage of the plant is only 328 kWh per year. The monthly power generated in this model is given in the Fig. 21.

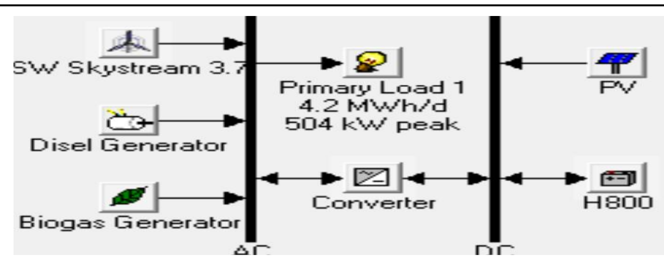

Fig. 20. System Configuration of Solar PV - Wind - Biomass - Diesel Hybrid System

TABLE 11
PRODUCTION DATA

Component	Production (kWh/yr)	Fraction
PV array	904,652	49%
Wind turbines	8,339	0.4%
Diesel Generator	13,148	0.6%
Biogas Generator	909,601	50
Total	909,601	100

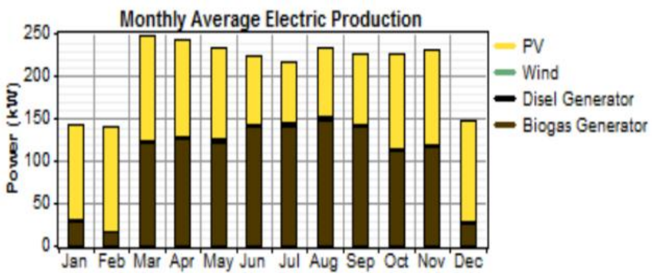

Fig. 21. Monthly Average Electrical Production of Solar PV - Wind - Biomass - Diesel Hybrid System

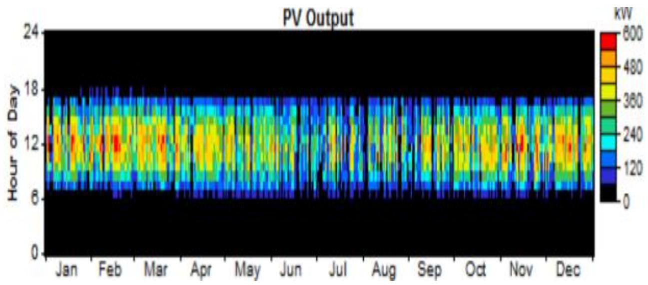

Fig. 22. Monthly Average Electrical Production of Solar PV - Wind - Biomass - Diesel Hybrid System

The capacity factor and the total production of the solar PV are 17.2% and 904,652 kWh/yr respectively. The variability of PV operation throughout the year is shown in the Fig. 22.

The capacity factor and the total production of the wind turbine are 17.6% and 8339kWh/yr respectively. The wind penetration is assumed as 0.548%. The variability of PV operation throughout the year is shown in the Fig. 23.

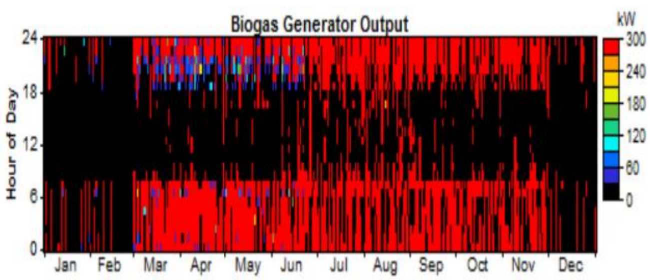

Fig. 23. DMap showing the variability of biogas generator output in Solar PV - Wind Biomass - Diesel Hybrid System throughout the year

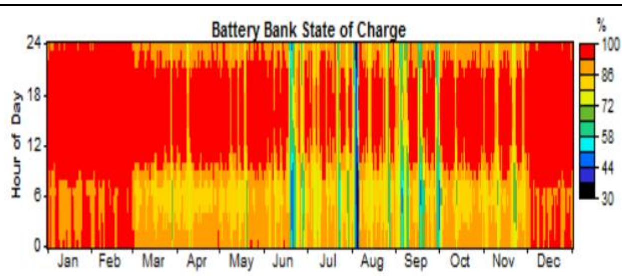

Fig. 24. DMap of State of charges of the batteries for various hours in a day for Solar PV - Wind - Biomass - Diesel Hybrid System

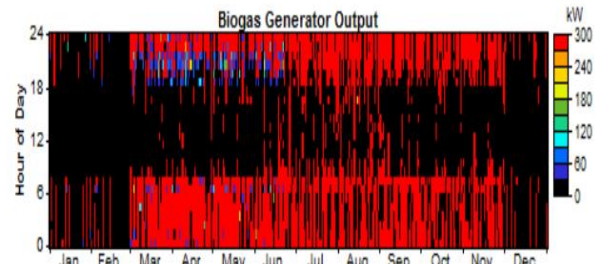

Fig. 25. Map showing the variability of biogas generator output in Solar PV - Wind Biomass - Diesel Hybrid System throughout the year

TABLE 12
EMISSION ANALYSIS

Pollutant	Emissions (kg/yr)
Carbon dioxide	13886
Carbon monoxide	52.7
Unburned hydrocarbons	5.84
Particulate matter	3.97
Sulfur dioxide	26.8
Nitrogen oxides	470

In this model 2000 batteries in each string where each string contains about 1000 batteries. As each batteries voltage is about 2V, the bus voltage is about 4V. The state of charge of the batteries in different times of the batteries and the variability of biogas generator output in Solar PV - Wind Biomass - Diesel hybrid System throughout the year are shown in the Fig. 24 and Fig. 25.

Emissions of various toxic gases are the least in this hybrid configuration in comparison to standalone diesel generators and all other configurations discussed above. However, emissions due to incorporating diesel generators & biogas generators of various GHGs and other toxic gases are quite considerable for the ecology and environment of St. Martin Island. From the Table 12, yearly CO2 emission is more than 13000kg and CO emission is more than 50kg per year.

7 RESULT

This part includes the comparison between the all possible solution and chosing the best solution among them.

7.1 Comparison among all possible configurations

Various types of standalone & hybrid system configurations are possible with the corresponding resources that we have considered for St. Martin Island. Comparison among all the possible system configurations is shown in the Table 13.

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TABLE 13

COMPARISON BETWEEN ALL POSSIBLE SOLUTIONS

System Configuration	Net Present Cost (Tk.)	Operating Cost (Tk/year)	Cost of Energy (Tk./ KWh)	CO_2 emission (Kg)	CO (Kg)	Renewable Fraction	Required area
Standalone Diesel	819,815,552	63,829,616	42.17	1,905,571	4704	0	Small
Standalone Biomass	475,312,672	31,706,278	24.45	937	35.2	1	Large
PV-Battery hybrid	390,688,640	4,043,434	20.10	0	0	1	Very Large
PV-Diesel-Wind-Battery	374,978,080	15,526,289	19.292	405,267	1,000	0.804	Moderate
PV-Diesel-Battery	317,062,336	10,487,258	16.32	230,726	570	0.909	Large (If PV is decentralized)
PV-Biomass-Battery	315,995,776	19,165,216	16.25	720	27	1	Large
PV-Biomass-Diesel-Battery	293,990,880	16,548,147	15.12	46,104	135	0.974	Large
PV-Biomass-Diesel-Wind-Battery	292,348,064	14,620,421	15.04	13,886	52.7	0.993	Moderate (If PV is decentralized)

Fig. 26. Hybrid System Implementation and Plant Distribution

7.2 Most Feasible solution for St. Martin Island

Solar PV-Wind-Diesel-Biomass Hybrid configuration is the most feasible solution for St. Martin Island. This decision has been come out by considering the following facts:

- Least Cost of Energy & least Net present cost.
- Incorporated with maximum sources
- Peak load can be easily compensated
- High renewable fraction (99.3%)
- Least CO2 emission
- Can be extended in future
- Requires less space if PV is decentralized
- Can make the St. Martin Island a Renewable Hub.
- If an investor invests in this project, he can make up his capital within 13 years. As project lifetime is 25 years, he can make profit on the rest 12 years.

7.3 Hybrid system implementation and plant distribution in St. Martin Island

The total load can be divided into 5 zones according their population and the size of area.

- Load Zone 1: Pashim Para
- Load zone 2: Uttar Para
- Load zone 3: Purba Para & Bazar Ghat (Most priority load zone)
- Load zone 4: Mazer Para
- Load zone 5: Dakshin Para.

Every zone has been incorporated with individual solar-battery hybrid plant and connected with Local transmission grid which has been supplied electricity from the main Power generating station. Main Power Station can be established in Marine Park, Golachipa which can be configured with Biogas generators, Diesel Generators and Wind mills.The whole configuration is sceened in Fig. 26.

8 CONCLUSION

Our main objective of this project is to show the satisfactory role of hybrid power system in St.Martin Island to decrease the cost of energy. The cost of the system and the energy cost per KWh are decreased by implementing hybrid power system instead of investing in diesel generator only.

Solar PV-Wind-Diesel-Biomass-Battery hybrid configuration has been proved as the most feasible solution for St.Martin Island because it has the least cost of energy produced (about BDT 15 per unit) & least net present cost comparing to the other hybrid models and stand-alone generation systems. It is incorporated with maximum sources where peak load can be compensated easily. It uses renewable sources mostly and it has a high renewable fraction (99.3%). It reduces carbon emissions significantly. In comparison to standalone diesel generators, this system is more eco-friendly and less polluting.

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