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An Efficient Solar-Wind-Diesel-Battery Hybrid Power System for St. Martin Island of Bangladesh

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Abstract- St. Martin's island is a small island in the Bay of Bengal about 17 km far from the main land of Bangladesh. Nearly 6000 inhabitants live there and fishing is their primary livelihood and as a tourist spot there are many hotels and rest houses. Since the island is far away from the main landgrid connection is almost impossible even in future due to its geographical position. However, the electricity demand is partly fulfilled by stand-alone diesel generators. In this study, an attempt has been made to model a hybrid electricity generation system for a small community of the island. This system incorporates a combination of solar PV, wind turbine, battery and diesel generator. HOMER, software for optimization of renewable based hybrid systems, has been used to find out the best technically viable renewable based energy efficient system for 100 households and 10 shops. Sensitivity analysis is also done to see the impact of solar insolation, PV investment cost, wind speed and diesel fuel price on the optimum result. This system can reduce CO2 emission by about14 tons per year compared to diesel generator only.

Keywords- Diesel Generator, HOMER, Hybrid System, Solar, Wind Turbine.

1. Introduction

St Martin's is one of the most beautiful tourist islands in Bangladesh where grid connected electric system for the inhabitants will not be possible to establish even in future. Diesel, kerosene and wood are the main fuels for fulfilling the energy demand. Solar and wind resources are the hybrid options for the Island. Saint Martin's Island is located on the southern-most tip of Bangladesh, roughly between 20° 34² - 20° 39² N and 92° 18² - 92° 21' E and 17 kilometers off Taknaf, the most southern main land of Bangladesh. The island is very much resourceful with enormous biological diversity such as existing fauna and flora Coral, Mollusk, Fish, Amphibian, Turtle, Snail, Bird and Mammals. Besides above coconut tree is the important cash crop [1]. Recently government has taken decision to formulate a master plan for development and protection of bio-diversity of St Martin's island and also to build several establishments for the tourism development at St Martin's island [2]. A survey was done by the Sustainable Rural Energy (SRE) program of Local Government Engineering Department (LGED) in 2004 and recorded that the population of the Island is 5196 where most of them are fisherman and they belong to 778 families. The annual electric energy demand was found about 359MWh [3]. There is a 30 KW diesel generator in St. Martins Island installed by PDB, but it is not running [4] People meet there energy demand through kerosene, coconut palm or by other biomass plants. Some of the commercial shops and hotels meet their electricity demand by diesel generator. The island has a good potential of solar and wind energy resources. But till now there has no such activity to use these resources. Therefore HOMER (Hybrid optimization Model for Electric Renewables), a software developed by National Renewable Energy Laboratory (NREL), USA for micro-power optimization model, has been used to find out the best energy efficient renewable based hybrid system options for the island. It contains a number of energy component models and evaluates suitable technology options based on cost and availability of resources [5]. The island has a good potential of solar and wind resources. Keeping these things in mind HOMER (Hybrid Optimization Model for Electric Renewables), software has been used to find out the best energy efficient renewable based hybrid system options for the island. Input information to be provided to HOMER includes: electrical load (primary energy demand), renewable resources (solar radiation, wind speed data), component technical details, cost, constraints, controls etc. The software designs an optimal configuration to serve the desired electric loads. To design the optimum system HOMER performs thousands of hourly simulations. HOMER also performs sensitivity analysis to see the impact of solar insolation, PV investment cost, wind speed and diesel fuel price on the COE [10].

2. Data Analysis on Available Renewable Energy Sources in St. Martin

There is no ground measurement data of solar radiation for the Island. But from the NASA satellite, it has been found that the annual solar insulation over St Martin is 4.84 kwh/m^2/day [6].

An estimation of solar insulation on horizontal surface has been done by using well known Angstrom Correlation and the sunshine hour data of Teknaf, Bangladesh Meteorological Department, the nearest meteorological station from St Martin's. Also a method has been developed by DLR, Germany which is a combination of DLR / SUNY – model output for Global Horizontal Insulation (GHI) is sampled for 10 km spatial resolution, and the calculated data has been collected from the SWERA Geospatial Toolkit for Bangladesh, developed under the SWERA project [7].

Table 1 shows the values of monthly solar insulation on horizontal surface for St Martin, observed from NASA for the period of 10 years (1983 – 1993) and estimated values from Teknaf sunshine data, also for 10 years (1992 – 2001). DLR method used three years (2000, 2002, 2003) satellite data for cloud cover, aerosol optical depth, water vapor to calculate GHI.

For Wind resources information, Bangladesh Council for Scientific and Industrial Research (BCSIR) has measured wind speed for the period of three years (1999 – 2001) at a height of around 30 meters above the ground level. Table 2 shows the monthly averaged measured wind speed at 30 m height and the NASA values for the same location at 10m height for terrain similar to airport. It has been found that wind speed goes to maximum and minimum at around 10 o'clock in the night and morning of local time respectively.

Biomass could be an alternative for energy sources. There are about 9000 coconut trees and 470 different kinds of fruit trees in the Island [1]. But for the analysis biomass has not been considered as the production seems not to be sufficient. Seven tidal gauge stations were set up by Bangladesh University of Engineering and Technology (BUET) for the feasibility study of tidal energy [8]. But the result was not in favor. So, only the solar and wind sources have been considered to find out the best hybrid options of renewable based efficient system.

Table 1. GHI values for St. Martin's island.

Months	NASA	Estimated	DLR
January	4.84	4.00	4.63
February	5.46	4.44	5.04
March	6.41	5.37	5.62
April	6.48	5.87	6.47
May	5.96	5.43	4.94
June	3.60	4.01	3.39
July	3.62	3.87	3.31
August	3.69	3.95	3.78
September	4.34	4.09	3.96
October	4.72	4.21	4.28
November	4.42	3.72	4.54
December	4.54	3.75	4.16
Average	4.84	4.40	4.50.

Table 2. GHI values at major cities of Bangladesh.

Months	Dhaka	Rajshahi	Sylhet	Chitta gong	Barishal
January	4.03	3.96	4.00	4.01	4.17
February	4.78	4.47	4.63	4.69	4.81
March	5.33	5.88	5.20	5.68	5.30
April	5.71	6.24	5.24	5.87	5.94
May	5.71	6.17	5.37	6.02	5.75
June	4.80	5.25	4.53	5.26	4.39
July	4.41	4.79	4.14	4.34	4.20
August	4.82	5.16	4.56	4.84	4.42
September	4.41	4.96	4.07	4.67	4.48
October	4.61	4.88	4.61	4.65	4.71
November	4.27	4.42	4.32	4.35	4.35
December	3.92	3.82	3.85	3.87	3.95
Average	4.73	5.00	4.54	4.85	4.71

Table 3. Wind speed data for St. Martin's island in m/s.

Months	NASA(10m)	Measured	V_{max}
January	3.27	5.03	23.32
February	3.39	4.70	19.78
March	3.57	4.24	18.94
April	3.67	3.79	20.03
May	3.89	5.07	26.30
June	6.27	6.17	29.80
July	6.35	5.56	24.20
August	5.64	5.78	20.40
September	4.05	4.47	17.70
October	3.27	4.11	15.90
November	3.24	3.53	14.50
December	3.10	4.11	15.20
Average	4.14	4.71	20.51

3. Hybrid Renewable Energy System

In this study solar and wind energy has been used with a diesel generator. The hybrid system consists of an electric load, renewable energy sources (solar and wind) and other system components such as PV, wind turbines, battery, converter [11]. Fig. 1 shows the complete hybrid energy renewable system.

In this study, a community of 100 households and 10 shops has been considered. This load is based on 3 energy efficient lamps (compact fluorescent bulb, 15 W each), 1 fan (ceiling fan, 40 W), and 1 television (TV, 40 W) for each family and 2 energy efficient lamps (15 W each), 1 fan (40 W) for each shop and overall 2 refrigerators (150 W each). Figures 3 & 4 show two load profiles on a day of winter (January) and summer (July).Measured hourly load profiles are not available, so load data were synthesized by specifying typical daily load profiles and then adding some randomness of daily 10% and hourly 15% noise. These have scaled up the annual peak load to 20 kW and primary load to78 kWh/day.

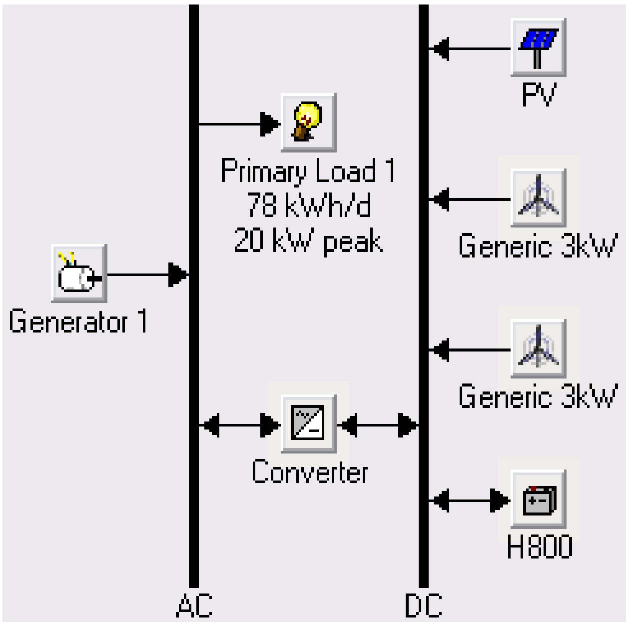


Fig. 1. Complete hybrid renewable energy system.

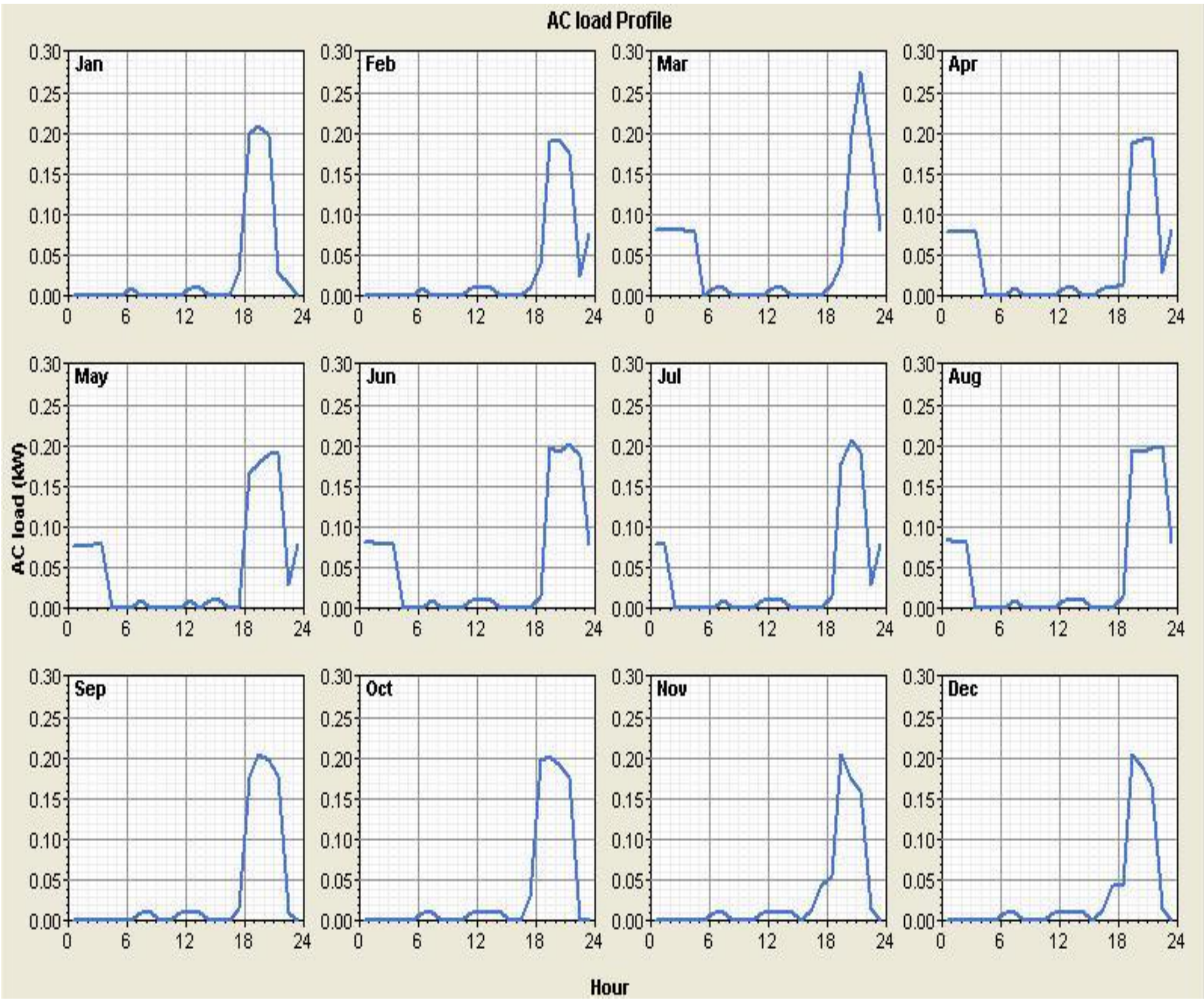


Fig. 2. Average hourly load profile for a single home user.

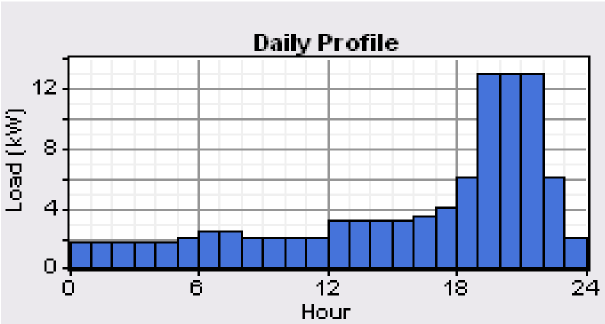


Fig. 3. Load profiles on a day of winter (January).

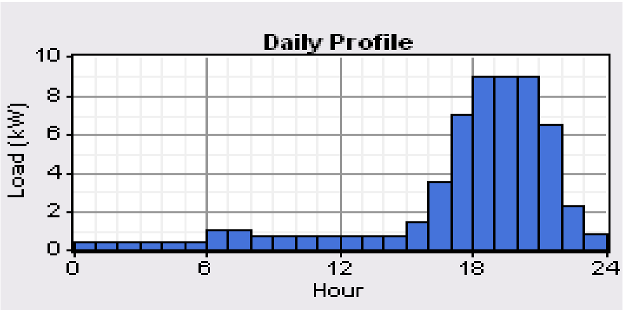


Fig. 4. Load profiles on a day of summer (July).

4. Hybrid System Component

4.1. Solar Energy

As hourly data is not available therefore monthly averaged global radiation data has been taken from NASA (National Aeronautics and Space Administration) [12]. HOMER introduces clearness index from the latitude and longitude information of the selected site. HOMER creates the synthesized 8760 hourly values for a year using the Graham algorithm. Fig. 5 illustrates that the solar radiation is high between February to April. The average annual clearness index is 0.484 and the average daily radiation is to 4.549 kWh/m2/d.

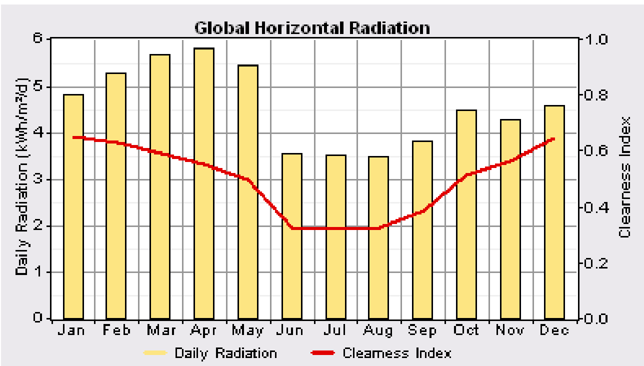
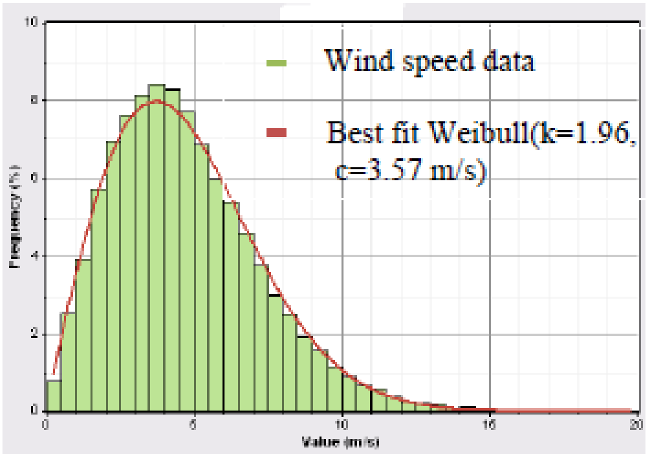


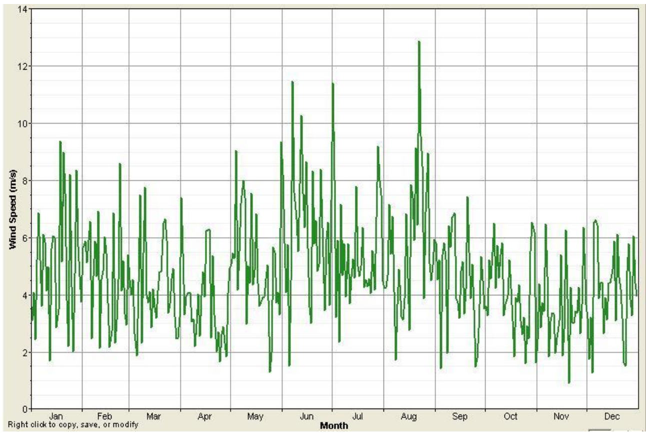
Fig. 5. Solar radiation data throughout the year.

4.2. Wind Energy

When hourly data is not available, hourly data can be generated synthetically from the monthly averages. HOMER's synthetic wind speed data generator is a little more different to use than the solar data because it requires four parameters [13]. The Weibull value: k value is a measure of distribution of wind speed over the year. In this study the value of k is taken as 2. The autocorrelation factor: This factor measures the randomness of the wind. Higher values indicate that the wind speed in 1 h tends to depend strongly on the wind speed in the previous hour. Lower values mean that the wind speed tends to fluctuate in a more random fashion from hour to hour. The autocorrelation factor value is taken as 0.78. The diurnal pattern strength: It is the measure of how strongly the wind speed depends on the time of the day. In this study, 0.30 is used. The hour of peak wind speed: It is simply the time of day tends to be windiest on an average throughout the year. In this study, 14 is used as the hour of peak wind speed [14].



(a)



(b)

Fig. 6. (a) Wind speed probability density function (b) daily wind speed for St Martin.

5. Data in Homer Software for Different Component

The major components of hybrid energy system are PV panels, wind turbines, diesel generator, batteries and converters. For economic analysis , the number of units to be used, capital costs, replacement and O&M costs and operating hours to be defined in HOMER in order to simulate the system.

5.1. Solar Photovoltaic

The cost of PV module including installation has been considered as Tk. 250 /W for Bangladesh. Life time of the modules has been taken as 25 years.8 kW and 10 kW PV modules are considered. The parameters considered for the simulation solar PV are furnished in table 4.

Table 4. Solar PV array-technical parameters and cost assumption.

Parameter	Value
Capital cost	250 Tk/W
Replacement cost	200 Tk/W
Operation and maintenance cost	50 Tk/W/yr
Lifetime	25 Years
Derating factor	90 %
Tracking System	No Tracking System

5.2. Diesel Generators

The fuel used in HOMER is modeled by a linear curve characterized by a slope and and intercept at no load. For a capacity range of 15 kW to 45 kW, the slope and the intercept are 0.33 l/h/kW and 0.05 l/h/kW respectively [15]. A diesel generator of 15 kW rated power with technical and economic parameters furnished in table 5.

Table 5. Technical parameters and cost assumptions for diesel generators.

Parameter	Value
Capital cost	10,000 Tk/KW
Replacement cost	8,000 Tk/W
Operation and maintenance cost	30(15KW) Tk/W
Lifetime	15,000 Hours
Minimum load ratio	10%
Fuel curve Intercept	0.05 1/h/KW_{rated}
Fuel curve slope	0.331/h/KW_{output}
Fuel price	56 Tk/liter

5.3. Wind Turbine

For the hybrid system a Generic 3 kW wind turbine has been considered [16]. Technical and economic parameters for selected wind turbine are furnished in table 6.

5.4. Battery

The Hoppecke 8 OPzS storage batteries are utilized in the hybrid system [17].The specifications like life time, efficiency, rectifire capacity and efficiency, capital and replacement cost are shown in table 7.

Table 6. Technical and economic parameters of wind turbine.

Parameter	Value
Rated power	3 KW
Starting wind speed	4 m/s
Rated wind speed	13 m/s
Cut-off wind speed	15 m/s
Capital cost	200,00 Tk/KW
Replacement cost	150,00 Tk/KW
Operation and maintenance cost	10,000 TK/year/turbine
Lifetime	20 Years

Table 7. Technical parametersand cost sssumption for battery.

Parameter	Value
Lifetime	10 Years
Efficiency	90%
Rectifier capacity	95%
Rectifier Efficency	85%
Capital cost	7,000 Tk/KWh
Replacement cost	6,000 Tk/KWh

6. Hybrid System Control Parameters and Constraints

The project life has been considered to be 25 years and the annual real interest has been taken as 5%.The capacity shortage penalty is not considered. The spinning reserve and system constraints are furnished in table 8 and 9 respectively.

Table 8. Spinning reserve Inputs.

Percent of annual peak load	0
Percent of hourly load	8
Percent of hourly solar output	0
Percent of hourly wind output	35

Table 9. Constraints used in HOMER.

Parameter	Value
Maximum unreserved energy	0(%)
Maximum renewable fraction	0 to 100%
Maximum battery life	N/A
Maximum annual capacity storage	5%

7. Optimization Result

To evaluate the performances of different hybrid systems in this study, optimal systems' performance analysis have been carried out using HOMER simulation tools. In this software the optimized results are presented categorically for a particular set of sensitivity parameters like solar radiation, wind speed, diesel price, maximum annual capacity shortage and renewable fraction. HOMER performs thousands of hourly simulations over and over in order to design the optimum hybrid system. Simulations have been conducted considering different values for solar radiation, wind speed, minimum renewable fraction, and diesel price providing more flexibility in the experiment. The optimization results for specific wind speed 4.71m/s, solar irradiation parameters 4.5486kWh/m2/d and diesel price 56 taka are illustrated in fig. 7. It is seen that a PV, wind turbine, diesel generator and battery hybrid system is economically more feasible with a minimum COE of tk.26.54/kWh and a minimum NPC of 10,620,388Tk. The hybrid system comprised of 8 kW PV array, two wind turbines (3 kW each), a diesel generator with a rated power of 15 kW and 25 storage batteries in addition to 10 kW converter is found to be the most feasible system. Fig. 8 shows the details related to energy generated by PV, wind turbine and diesel generator system, excess electricity, un-met load, capacity shortage and renewable fraction for the most economically feasible system applicable for the selected location.

Sensitivity variables

Global Solar (kWh/m²/d) 4.55 | Wind Speed (m/s) 4.71 | Diesel Price ($/L) 56

Max. Annual Capacity Shortage (%) 0

Double click on a system below for simulation results. ○ Categorized ◉ Overall Export...

PV (kW)	G3	G3	Gen1 (kW)	H800	Conv. (kW)	Disp. Strgy	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage	Diesel (L)
8	1	1	15	25	10	CC	$ 2,979,330	542,152	$ 10,620,388	26.539	0.31	0.00	7,787
8	1	1	15	30	10	CC	$ 3,035,330	539,031	$ 10,632,407	26.575	0.31	0.00	7,735
8	1	1	15	25	15	CC	$ 3,053,995	547,821	$ 10,774,954	26.928	0.29	0.00	7,868
8		1	15	30	10	CC	$ 2,835,330	565,547	$ 10,806,119	27.006	0.26	0.00	8,252
8		1	15	25	10	CC	$ 2,779,330	570,407	$ 10,818,620	27.032	0.25	0.00	8,329
10	1	1	15	25	10	CC	$ 3,479,330	521,889	$ 10,834,804	27.077	0.34	0.00	7,466
8	1		15	30	10	CC	$ 2,835,330	567,965	$ 10,840,195	27.091	0.26	0.00	8,252
10	1	1	15	30	10	CC	$ 3,535,330	518,410	$ 10,841,770	27.098	0.34	0.00	7,378
8	1	1	15	25	18	CC	$ 3,098,794	550,019	$ 10,850,735	27.117	0.29	0.00	7,872
8	1		15	25	10	CC	$ 2,779,330	572,825	$ 10,852,695	27.117	0.25	0.00	8,329
8	1	1	15	20	10	CC	$ 2,923,330	562,629	$ 10,852,989	27.119	0.29	0.00	8,059
8	1	1	15	20	15	CC	$ 2,997,995	559,787	$ 10,887,596	27.206	0.29	0.00	8,013
8	1	1	15	20	18	CC	$ 3,042,794	561,641	$ 10,958,537	27.383	0.29	0.00	8,013
8	1	1	15	30	15	CC	$ 3,109,995	557,343	$ 10,965,158	27.397	0.28	0.00	7,988
10		1	15	30	10	CC	$ 3,335,330	542,766	$ 10,985,048	27.447	0.29	0.00	7,869
8		1	15	25	15	CC	$ 2,853,995	577,079	$ 10,987,316	27.457	0.24	0.00	8,398
8		1	15	20	10	CC	$ 2,723,330	586,396	$ 10,987,968	27.457	0.25	0.00	8,522
10		1	15	25	10	CC	$ 3,279,330	547,016	$ 10,988,939	27.466	0.29	0.00	7,940
10	1	1	15	25	15	CC	$ 3,553,995	527,567	$ 10,989,491	27.460	0.32	0.00	7,542

Fig. 7. Optimization results for PV-diesel-wind turbine-battery system for a solar radiation of 4.549 kWh/m2/d,diesel price of 56 Tk./L, maximum capacity shortage of 0%.(All the currency values were in terms of Tk)

System Architecture: 8 kW PV | 15 kW Generator 1 | 9.5 kW Rectifier
1 Generic 3kW | 25 Hoppecke 8 OPzS 800Cycle Charging
1 Generic 3kW | 10 kW Inverter

Total NPC: $ 10,620,388
Levelized COE: $ 26.539/kWh
Operating Cost: $ 542,152/yr

Cost Summary | Cash Flow | Electrical | PV | G3 | G3 | Gen1 | Battery | Converter | Emissions | Time Series

Production	kWh/yr	%
PV array	12,882	34
Wind turbines	5,312	14
Generator 1	19,704	52
Total	37,899	100

Consumption	kWh/yr	%
AC primary load	28,394	100
Total	28,394	100

Quantity	kWh/yr	%
Excess electricity	5,024	13.3
Unmet electric load	3.19	0.0
Capacity shortage	9.74	0.0

Quantity	Value
Renewable fraction	0.306
Max. renew. penetration	2,871 %

Fig. 8. Energy generated by PV, wind turbine and diesel generator system, excess electricity, un-metload, capacity shortage and renewable fraction.

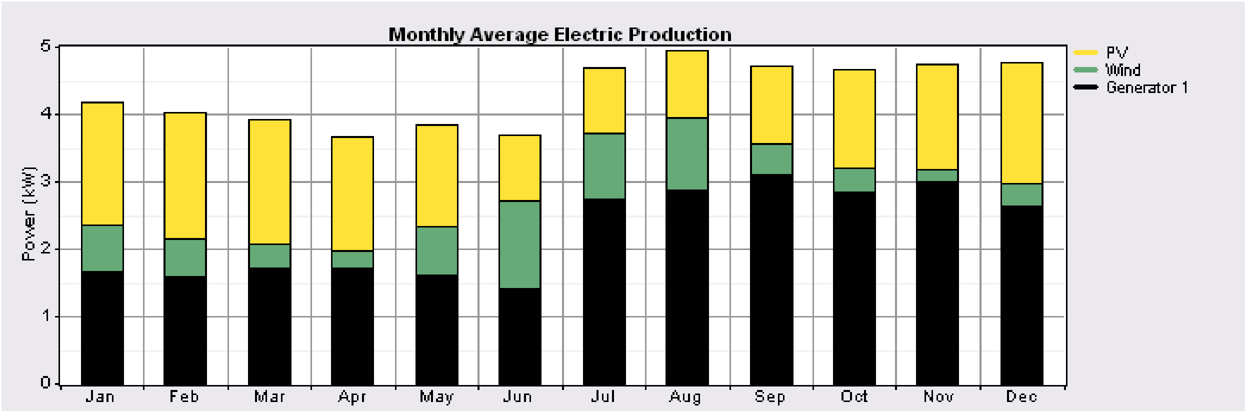


Fig. 9. Energy yield for the feasible hybrid PV-diesel-wind-battery system.

8. Conclusion

The study simulates a PV-wind –diesel-battery hybrid energy system in St. Martin's Island**.** The optimized hybrid energy system was developed considering manufacturing cost and efficiency. The result shows that the COE of the optimized system is Tk. 26.54/kWh.This system gives better performance than the other system because if any fault occur in PV panel or in wind turbines then the generator can minimize this problem.

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