An Optimized Stand-alone Green Hybrid Grid System for an Offshore Island, Saint Martin, Bangladesh

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***Abstract*—Saint Martin's island is the largest offshore island of Bangladesh which is one of the most beautiful tourist spots in the world. But as the island is far away from the mainland, it is not connected to the main grid of the country. This paper proposes an optimized stand-alone green hybrid system to supply electricity for the inhabitants & tourists of the island. Considering 1000 households for all of its inhabitants and 200 hotel rooms for tourists, the average daily load is 1135.82 kWh/day with an annual peak load of 227.76 kW. The aim of this paper is to design the most cost efficient optimized stand-alone green hybrid system which provides zero emission and 100% renewable fraction. HOMER(Hybrid Optimization Model for Multiple Energy Resources) is used to design this system. The simulation results show that a hybrid system with 659 kW PV array, 3073 strings of batteries, 245 kW converter forms the most optimized stand-alone system with COE(Cost of Energy) of $0.266 and NPC(Net Present Cost) of $1379832. Significantly, energy cost of the proposed system is viable in context with socio-economic condition of the country which will eventually provide the power solution maintaining the scenic beauty of the island.**

***Index Terms*—Optimized Stand-alone system, green hybrid system, COE, NPC, zero emission.**

I. INTRODUCTION

Saint Martin is one of the most eminent tourist places of Bangladesh which is located in the southern most part of Bangladesh. It is located about 9 km away from the main land of Cox's Bazar-Teknaf peninsula on the north-eastern part of Bay of Bengal [1]. This island is located between 20°34′N-20°37′N & 92°18′E-92°21′E. According to the socio-economic monitoring report for Saint Martin's island, Bangladesh(2015)- the island holds around 8000 inhabitants in around 1200 households. Around 2000-3000 of these people settle in the island seasonally for tourism and construction related activities. This place is renowned for its natural beauty and bio-diversity it provides. But this place could offer more to the tourists and inhabitants if this place had the power supply from the grid or offshore stand-alone system. Due to the lack of comfort accommodation, this beautiful tourist spot is loosing its attraction which can be gained only by a viable power solution for the island. Electricity transmission from main grid is quite impossible as it is around 9 km away from the main land. People here use localized PV cell on a small scale and diesel generator for very limited time and emergency purposes only. But sufficient power supply is needed to attract the tourists and also for the ease of the inhabitants. Due to its distance from the mainland, offshore grid is the only feasible solution. Holding this aspiration, BPDB(Bangladesh Power Development Board) launched a 30 kW diesel generator in St. Martin's island but unfortunately this is not working anymore [2].

Our proposed stand-alone green hybrid grid can provide electricity for its population and tourists as well. There is no meaning of providing electricity to comfort the inhabitants and tourists if the production procedure itself destruct the natural beauty and calmness. Besides the world is stake of carbon-di-oxide emission which is degrading the global warming situation. So we are proposing a system which is 100% green thus the carbon-di-oxide emission is zero. Our proposed system also offers no sound pollution even which maintains the natural beauty and charm of the island which is attracting the tourists.

This island has good potential resources of solar and wind energy. Thus, with the aspiration of having a greener world with zero carbon emission we considered solar cell, wind turbine generator and batteries as our potential power sources of our system as shown in fig. 1. Moreover, for operational and planning purposes in large/short-scale network, it is needed to analyze optimal power study [3]. So we optimized our system with HOMER(Hybrid Optimization Model for Multiple Energy Resources) software to find the most cost efficient green hybrid system for the island. Electrical loads, components to be used, solar radiation data, wind speed profile and technical details of the components are to be provided to the software to design the system.

HOMER then performs simulations based on the given data to find the most cost efficient and optimized system. HOMER

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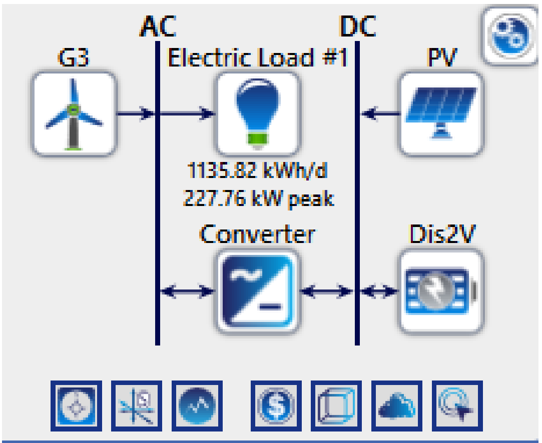


Fig. 1. Green hybrid energy system

also provides the sensitivity analysis to see the impact of each and every factors like wind speed, solar exposure, components longevity, fuel price etc. on Cost of Energy (COE). It also performs the economic analysis to rank the system based on their Net Present Cost(NPC) [4]. But HOMER is subject to ignore the changes which are less than 1 hour of time which doesn't even fluctuate the real life scenario that much.

II. Load Data Modeling and Analysis

There is no power grid system in the island from the government side. Rather people generate their own electricity locally with PV cell and small diesel generator which is very negligible in compared to their demand. Previously, work is done considering the demand of 100 households & 10 shops or only considering the hotel rooms for tourists to make an optimized model for the island [1] [2]. But to give a realistic and complete power solution to the island, we are considering the whole population and the tourists to model the daily load demand. We have proposed the load data modeling to provide power to all the inhabitants and tourists uninterruptedly.This realistic data modeling and optimized data solution which completely green- is the uniqueness of the proposed system.

People usually travel to Saint Martin's island within November to March. For the rest of the time of the year government has banned the traveling to the island for their safety purpose as the climate is not suitable for the tourists. Moreover, 2000-3000 inhabitants of the island are seasonal and they only live

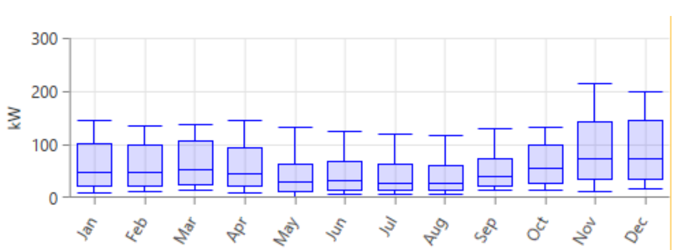


Fig. 2. Monthly load profile

in island in the tourist season for business purpose. Keeping all these in mind and considering the socio-economic condition of the inhabitants we have modeled the daily load profile for 1000 households and 10 hotels-each hotel having 20 rooms for tourists. The assumed appliances, their quantity, capacity and average power consumed per day by a household and a hotel room are depicted in table I & table II respectively [2].

TABLE I
Appliances for Single Household

Appliances	Capacity	Quantity	Average Work Hour Per Day	Average Power Consumption Per Day
Florescence Light	15 W	4	6	0.36 kWh
Fan	40 W	2	8	0.64 kWh
TV	40 W	1	3	0.12 kWh

TABLE II
Appliances for Single Hotel Room

Appliances	Capacity	Quantity	Average Work Hour Per Day	Average Power Consumption Per Day
Florescence Light	15 W	2	7	0.42 kWh
Fan	40 W	1	8	0.32 kWh
TV	40 W	1	3	0.12 kWh

The load data were analyzed to create the hourly load profile with a randomness of daily 10% and hourly 15% noise. HOMER synthesized the given hourly load to produce average monthly and yearly load profile. These have generated an average daily load of 1135.82 kWh/day with an annual peak load of 227.76 kW. Fig. 2 shows the monthly load profile considering 1000 households and 200 hotel rooms of Saint Martin's island.

III. Potential Green Energy Sources

The Saint Martin's island has good potential in solar energy and wind energy due to its geographic location. With a desire to keep the nature clean we haven't considered any energy sources that have any carbon emission. So we discarded the choice of diesel generator or gas turbine generator from our system. As we hope to provide a stand-alone hybrid grid system which is 100% green, solar PV cells, wind turbine generators and batteries are our only potential components.

A. *Solar Energy*

HOMER uses the geographic location of Saint Martin for calculating the solar radiation on island from clearness indices and vice versa. Monthly average global radiation data of Saint Martin island has been taken from NASA(National Aeronautics and Space Administration). When this data is given input, HOMER synthesizes solar radiation values of 8760 hours for each year using Graham algorithm [5]. The monthly average solar irradiance data of Saint Marin which is synthesized by HOMER is shown in the fig. 3. The annual average daily radiation is 4.80 kWh/m^2/day and average annual clearness index is 0.527.

B. Wind Energy

In our case, monthly average values can be used to synthesize hourly wind speed data. HOMER Synthetic wind speed data generator needs four parameters [6]. The Weibull value: It is denoted by k and it measures the distribution of the wind speed over the year. In our study we have taken the value of k as 2.

The autocorrelation factor: Randomness of wind is measured by this factor. The lower value of the factor means the wind speed changes more randomly. In our case, it is taken as 0.78.

The Diurnal pattern strength: This factor measures that, how much the wind speed depends on the time of the day. We have taken 0.30 as diurnal pattern strength.

The hour of peak wind speed : It is the most windiest time of the day on an average, throughout the year. We have used 14 as the hour of peak wind speed [7].

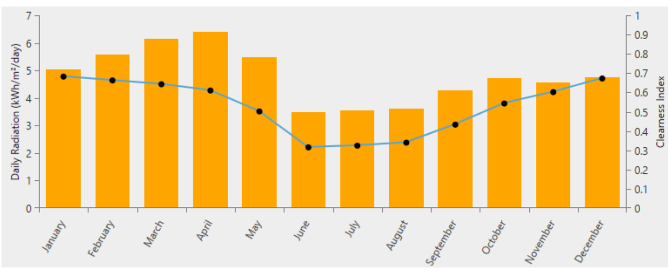


Fig. 3. Monthly average solar Global Horizontal Irradiance(GHI) of Saint Martin

Fig. 4 shows the monthly average wind speed data of Saint Martin island which is synthesized by HOMER from the data collected from NASA surface meteorology and solar energy database.

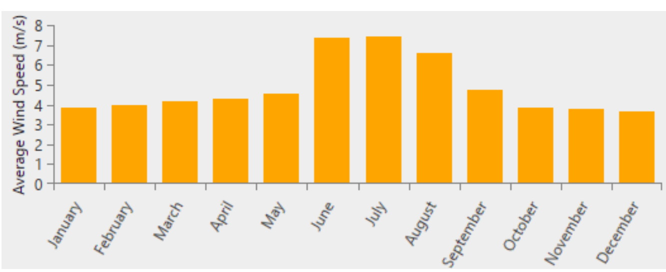


Fig. 4. Monthly average wind speed of Saint Martin

IV. Components of the Proposed Hybrid System

As our proposed system is 100% green, so we have considered PV array, wind turbines, storage batteries and converter in our system. For any reason, when the Solar cell or the wind turbine fail to generate the necessary power, storage batteries act as the backup component to give the power supply. For economic analysis technical ratings, capital cost, replacement and O&M(Operation and Maintenance) cost are to be given as input in HOMER.

A. Solar PV Modules

Generic 1 kW PV module is considered with the capital cost of $800 [8]. Technical details of the PV module is shown in the table III.

TABLE III
Technical Details of PV Module

PV	
Capital Cost	$800
Replacement Cost	$800
Operation and maintenance cost	10$/year
Lifetime	25 years
Derating factor	90%
Tracking system	No

B. Wind Turbine

We have considered a 3 kW generic wind turbine. The cost and the technical details of the component are depicted in the table IV [9].

TABLE IV
Technical Details of Wind Turbine

Wind Turbine	
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	$7500
Replacement Cost	$5625
Operation and maintenance Cost	125$/year
life time	20 years

C. Battery

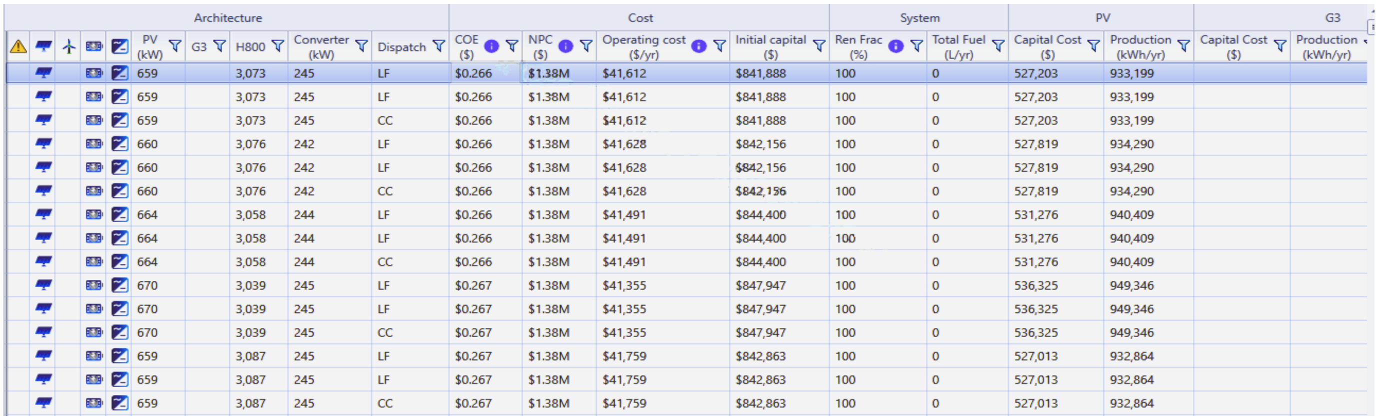
We have used Hoppecke 8 OPzS storage batteries in our green hybrid system. The technical details and costing of the battery are in table V [5].

TABLE V
Technical Details of Battery

Battery	
Nominal Voltage	2 Volt
Nominal capacity	1.92 kWh
Maximum charge current	162 A
Round-trip efficiency	86%
Minimum state of charge	30%
Capital cost	$87.5
Replacement cost	$75
Operation and maintenance cost	10$/year

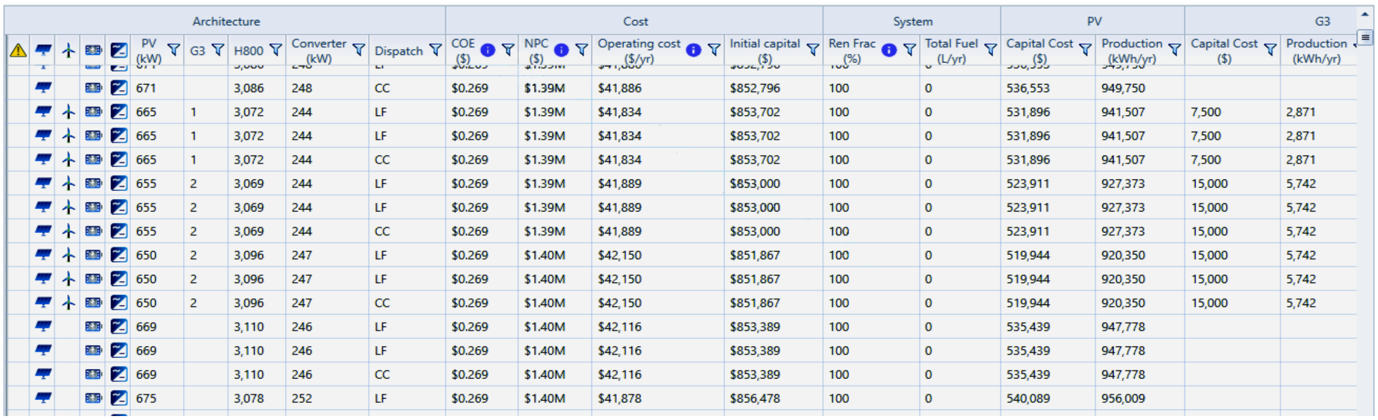
D. Converter

PV arrays and batteries are connected to the DC bus but wind turbine & the load of the consumers are of AC type & connected to AC bus. So we have used converter in our system to convert DC-AC and vice-versa. The technical and cost description of the converter are shown in table VI [1].



PV (kW)	G3	H800	Converter (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($/yr)	Initial capital ($)	Ren Frac (%)	Total Fuel (L/yr)	PV Capital Cost ($)	PV Production (kWh/yr)	G3 Capital Cost ($)	G3 Production (kWh/yr)
659		3,073	245	LF	$0.266	$1.38M	$41,612	$841,888	100	0	527,203	933,199		
659		3,073	245	LF	$0.266	$1.38M	$41,612	$841,888	100	0	527,203	933,199		
659		3,073	245	CC	$0.266	$1.38M	$41,612	$841,888	100	0	527,203	933,199		
660		3,076	242	LF	$0.266	$1.38M	$41,628	$842,156	100	0	527,819	934,290		
660		3,076	242	LF	$0.266	$1.38M	$41,628	$842,156	100	0	527,819	934,290		
660		3,076	242	CC	$0.266	$1.38M	$41,628	$842,156	100	0	527,819	934,290		
664		3,058	244	LF	$0.266	$1.38M	$41,491	$844,400	100	0	531,276	940,409		
664		3,058	244	LF	$0.266	$1.38M	$41,491	$844,400	100	0	531,276	940,409		
664		3,058	244	CC	$0.266	$1.38M	$41,491	$844,400	100	0	531,276	940,409		
670		3,039	245	LF	$0.267	$1.38M	$41,355	$847,947	100	0	536,325	949,346		
670		3,039	245	LF	$0.267	$1.38M	$41,355	$847,947	100	0	536,325	949,346		
670		3,039	245	CC	$0.267	$1.38M	$41,355	$847,947	100	0	536,325	949,346		
659		3,087	245	LF	$0.267	$1.38M	$41,759	$842,863	100	0	527,013	932,864		
659		3,087	245	LF	$0.267	$1.38M	$41,759	$842,863	100	0	527,013	932,864		
659		3,087	245	CC	$0.267	$1.38M	$41,759	$842,863	100	0	527,013	932,864		

Fig. 5. Optimization result for the hybrid system



PV (kW)	G3	H800	Converter (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($/yr)	Initial capital ($)	Ren Frac (%)	Total Fuel (L/yr)	PV Capital Cost ($)	PV Production (kWh/yr)	G3 Capital Cost ($)	G3 Production (kWh/yr)
671		3,086	248	CC	$0.269	$1.39M	$41,886	$852,796	100	0	536,553	949,750		
665	1	3,072	244	LF	$0.269	$1.39M	$41,834	$853,702	100	0	531,896	941,507	7,500	2,871
665	1	3,072	244	LF	$0.269	$1.39M	$41,834	$853,702	100	0	531,896	941,507	7,500	2,871
665	1	3,072	244	CC	$0.269	$1.39M	$41,834	$853,702	100	0	531,896	941,507	7,500	2,871
655	2	3,069	244	LF	$0.269	$1.39M	$41,889	$853,000	100	0	523,911	927,373	15,000	5,742
655	2	3,069	244	LF	$0.269	$1.39M	$41,889	$853,000	100	0	523,911	927,373	15,000	5,742
655	2	3,069	244	CC	$0.269	$1.39M	$41,889	$853,000	100	0	523,911	927,373	15,000	5,742
650	2	3,096	247	LF	$0.269	$1.40M	$42,150	$851,867	100	0	519,944	920,350	15,000	5,742
650	2	3,096	247	LF	$0.269	$1.40M	$42,150	$851,867	100	0	519,944	920,350	15,000	5,742
650	2	3,096	247	CC	$0.269	$1.40M	$42,150	$851,867	100	0	519,944	920,350	15,000	5,742
669		3,110	246	LF	$0.269	$1.40M	$42,116	$853,389	100	0	535,439	947,778		
669		3,110	246	LF	$0.269	$1.40M	$42,116	$853,389	100	0	535,439	947,778		
669		3,110	246	CC	$0.269	$1.40M	$42,116	$853,389	100	0	535,439	947,778		
675		3,078	252	LF	$0.269	$1.40M	$41,878	$856,478	100	0	540,089	956,009		

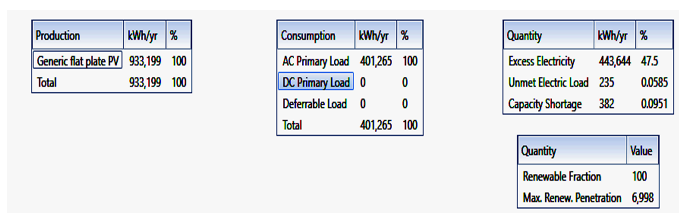
Fig. 6. Optimization result for the hybrid system (considering wind turbine)

TABLE VI
TECHNICAL DETAILS OF CONVERTER

Converter	
Capital Cost	186.66$/kW
Replacement cost	125$/kW
Lifetime	10 years
Efficiency	90%
Rectifier capacity	95%
Rectifier efficiency	85%

V. SIMULATION AND OPTIMIZATION RESULTS

HOMER conducted hours of simulations with different values of solar radiation, wind speed, taking different components in account at different times and came up with the optimized solution. It is found that, a hybrid system with 659 kW PV, 3073 string of batteries and 245 kW converter will be the most viable one considering each and every factor with the minimum COE of 0.266$/kWh and NPC of $1379832 when the solar radiation is 4.5 kWh/m^2/day and wind speed is 4.6 m/s. The renewable penetration of the system is 100% with no emission and no sound pollution which makes the system 100% green and eco-friendly. Fig. 5 shows the part of the optimized result of the system consisting of solar PV and battery whereas fig. 6 shows the system consisting of solar PV, wind turbine and battery. Our optimized system produces 933,199 kW/year with 100% renewable penetration and unmet load of only 0.0585%. Fig. 7 shows the details of the total



Production	kWh/yr	%
Generic flat plate PV	933,199	100
Total	933,199	100

Consumption	kWh/yr	%
AC Primary Load	401,265	100
DC Primary Load	0	0
Deferrable Load	0	0
Total	401,265	100

Quantity	kWh/yr	%
Excess Electricity	443,644	47.5
Unmet Electric Load	235	0.0585
Capacity Shortage	382	0.0951

Quantity	Value
Renewable Fraction	100
Max. Renew. Penetration	6,998

Fig. 7. Details of total electricity generation

electricity generation. The monthly electricity generation is shown in the fig. 8, which shows that the electric generation in the months of January, February and March are greater than any other months as these are the main tourism period for the island.

The simulated results for PV and battery generated by HOMER as a part of the whole system are depicted in the fig. 9 and fig. 10 respectively.

Now, in the optimization simulation HOMER discarded the wind turbine from the system to have the minimum COE. But

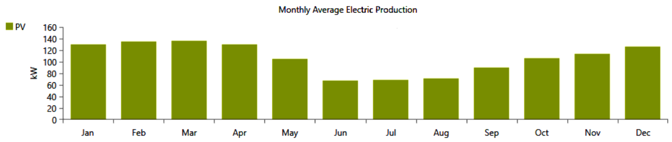


Fig. 8. Monthly electricity generation

Quantity	Value	Units
Rated Capacity	659	kW
Mean Output	107	kW
Mean Output	2,557	kWh/d
Capacity Factor	16.2	%
Total Production	933,199	kWh/yr

Quantity	Value	Units
Minimum Output	0	kW
Maximum Output	611	kW
PV Penetration	232	%
Hours of Operation	4,363	hrs/yr
Levelized Cost	0.0508	$/kWh

Fig. 9. Simulated results of PV

if we consider the wind turbine in our hybrid system, that will increase the COE to \$0.269. Percentage of COE increase =

$$\frac{COE\ with\ wind\ turbine - COE\ without\ wind\ turbine}{COE\ without\ wind\ turbine}$$

$\times 100\%$

$$= \frac{0.269 - 0.266}{0.266} \times 100\%$$

$$= 1.13\%$$

Thus the COE increases by 1.13% if we consider wind turbine in our system.

VI. Emission Analysis

As the name of our proposed system - optimized stand-alone green hybrid grid, our system produces zero emission to make the system totally green and eco-friendly. Fig. 11 shows the simulated emission result of our system.

If the diesel generator is also used in the system then the COE reduces to \$0.253 from \$0.266 [2]. But the renewable fraction decreases to 89% from 100%. Moreover, the emission increases in significant amount in compared to our optimized system. This is the trade-off we are to make between COE and emission.

VII. Conclusions

Our study simulates PV-battery energy system as the most efficient, optimized and cost efficient green stand-alone system for Saint Martin's island. A PV array of 659 kW, 3073 strings of batteries with nominal capacity of 1.92 kW & nominal voltage of 2V, a converter of 245 kW give most cost efficient system with zero emission and no sound pollution. The COE of our designed system is \$0.266 with 100% renewable fraction. The NPC and operating cost of our designed optimized system are \$1.38M and \$41,612 respectively. This system reduces the carbon emission to zero. Using a diesel generator in the system reduces the COE by a very small fraction but that increases the emission significantly and also increases the sound pollution.

Quantity	Value	Units
Batteries	3,073	qty.
String Size	1.00	batteries
Strings in Parallel	3,073	strings
Bus Voltage	2.00	V

Quantity	Value	Units
Autonomy	89.9	hr
Storage Wear Cost	0.0298	$/kWh
Nominal Capacity	5,885	kWh
Usable Nominal Capacity	4,119	kWh
Lifetime Throughput	5,962,801	kWh
Expected Life	20.0	yr

Quantity	Value	Units
Average Energy Cost	0	$/kWh
Energy In	320,189	kWh/yr
Energy Out	276,484	kWh/yr
Storage Depletion	1,209	kWh/yr
Losses	44,914	kWh/yr
Annual Throughput	298,140	kWh/yr

Fig. 10. Simulated results of battery

Quantity	Value	Units
Carbon Dioxide	0	kg/yr
Carbon Monoxide	0	kg/yr
Unburned Hydrocarbons	0	kg/yr
Particulate Matter	0	kg/yr
Sulfur Dioxide	0	kg/yr
Nitrogen Oxides	0	kg/yr

Fig. 11. Simulated emission result of the system

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