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An Efficient Solar Power Generation System for Chakaria Island of Bangladesh

Sk. Suzauddin Yusuf[1], Md. Washim Akram[1], Robiul Islam Rubel[1] and Md Redwan Islam[1]
[1] Department of Mechanical Engineering, Bangladesh Army University of Science and Technology, Saidpur-5310, Bangladesh
E-mail: washim@baust.edu.bd

Abstract

It is the international trend to promote renewable energy, as part of energy security as well as greenhouse gas emission reduction. Solar energy can be used to supplement the conventional energy sources predominantly in remote coastal localities of Bangladesh. Feasibility study of renewable resources of Chakaria, an off-grid remote island, is presented in this paper. Purpose of this study is to design, simulation and economic analysis of a stand-alone optimal mini-grid Solar power generation system in a remote island of Bangladesh to satisfy the energy demands as well as Greenhouse gas (GHG) reduction in a sustainable way by HOMER ENERGY software. The optimum size of different components, electrical load with a certain random variability, fraction of renewable energy, excess electricity, the performance of its different components, environmental impacts, cost of energy (COE), net present cost (NPC), annualized cost are analyzed in this paper. This proposed system can be a perfect long term solution to meet the energy demand in Chakaria island. Cost of electricity found from this simulation is 0.3362 $/kWh which is acceptable.

Keywords: Solar power, Mini-grid, Renewable energy, GHG reduction, HOMER optimizer.

1. Introduction

Due to crossing over from the list of least developed countries the electricity demand of Bangladesh is increasing day by day [1]. Till now, the amount of total population has come under electricity generation is 83% and per-capita generation has increased to 433 kWh. Bangladesh Power Development Board prepared generation expansion plan to achieve generation capacity 24,000 MW by 2021 with the aim to provide quality and reliable electricity to the all people across the country for desired economic growth and social development [2]. Since Bangladesh is facing to the depletion of domestic gas supply and drastic increase of fuel price, various issues such as sustainable development harmonizing with economic optimization, improvement of power quality, and the discipline of operation and maintenance for power plants need to be addressed holistically [3]. On the other hand, the effect of greenhouse gas and global warming are the main concern of scientists all over the world [4, 5, 6]. Besides, the rapid depletion of fossil fuel is another environmental issue which has already been investigated by different public and private organizations all over the globe [7, 8]. Thus it is a crying need to incorporate renewable energy for sustainable electricity generation in Bangladesh.

For St. Martin island of Bangladesh, the feasibility of solar-wind-diesel-battery hybrid power system was simulated by Habib Ullah and found that it was efficient for 100 households and 10 shops, besides sensitivity and emission analysis had been accomplished [9]. A solar-diesel hybrid power generation system for Kutubdia island of Bangladesh was designed, simulated by Yusuf et al. where it has been found that the electricity generation cost is 0.2386 $/kWh [10]. An optimal mini-grid solar-fuel cell hybrid power generation system for a remote island of Bangladesh had been designed and simulated by Yusuf et al. where it has been found that the electricity generation cost is 0.1276 $/kWh [11]. An off-grid wind-solar-diesel hybrid power system for Kutubdia island of Bangladesh had been designed and simulated by Datto using HOMER energy software. The electricity generation cost was 0.175 $/kWh [12]. An environment friendly off-grid wind-diesel hybrid power system in Kutubdia island of Bangladesh had been designed by Datto et al. which was cost effective and electricity generation cost was 0.209 $/kWh [13]. An optimized hybrid energy system was modeled for St. Martin island of Bangladesh where it has been found that the cost of energy is 0.345 $/kWh [14].

A solar-wind-diesel hybrid power system for rural areas of Bangladesh was designed and its performance as well as feasibility analyzed where it is found that the cost of energy is 0.822 $/kWh [15]. Das et al. found the cost of energy 0.161 $/kWh in a PV-wind-battery hybrid energy system in rural Bangladesh [16]. A PV-wind-diesel generator hybrid power system for a hilly region Khagrachari of Bangladesh had been designed, analyzed and

performance studied [17]. A technical and economic solar-wind hybrid energy system in coastal area of Chittagong, Bangladesh was studied where the result of sensitivity analysis has shown that 20% reduction of installation cost results in nearly 9%-12% reductions in cost of per unit energy [18]. An optimal solar-wind-diesel hybrid energy system for Kuakata of Bangladesh was designed where it has been found as feasible technology [19]. A techno-economic analysis of off-grid hybrid systems at Kutubdia island in Bangladesh was studied [20]. An optimized design of a hybrid PV-wind-diesel energy system for sustainable development of St. Martin island and Kuakata has been successfully studied where it is established that the cost of energy generation is 16% lower than the previously designed system [21]. A PV-biogas-diesel hybrid energy system for Adorsho Char island, Bangladesh was modelled where the cost of energy was 0.217 $/kWh [22]. In another study, an optimized hybrid energy system for Kutubdia island, Bangladesh was modelled and the cost of energy was 0.42 $/kWh [23].
However, from the best of the author's knowledge, there is no comprehensive study that investigated the feasibility of solar power generation system on Chakaria island of Bangladesh. Only about 40% of rural households have access to grid electricity [24]. Many remote localities along with the coastal areas are not connected to grid electricity. Renewable energy systems are becoming popular as stand-alone power systems for providing electricity in remote areas due to advances in renewable energy technologies and subsequent rise in prices of petroleum products [10]. A stand-alone optimal mini-grid power generation system is designed by using HOMER ENERGY software in which a feasible renewable energy technology is used to meet the electricity demand in a reliable and sustainable manner. Environment pollution is considerably reduced as compared to any conventional system, due to reduction of fossil fuel consumption.

2. Study Area

In Bangladesh, Chakaria is an Upazila of Cox’s Bazar district in the division of Chittagong. Total area of Chakaria is 643.46 km^2. Chakaria is bounded by Cox's Bazar Sadar, and Ramu Upazilas on the south, Lohagara, Banshkhali and Lama Upazilas on the north, Maheshkhali and Kutubdia Upazila on the west, Lama and Naikhongchhari Upazilas on the east. The Upazila is surrounded by Kutubdia, Bara Matamuhuri, Maheshkhali and Matamuhuri channel. The study area more often falls victim to cyclone and tidal bore. Chakaria is located at 21.7861ºN and 92.0778ºE. Total number of household in the study area is 63671. Once there was a mangrove forest named Chakaria Shundarban. But, now it is no more. According to Bangladesh Census, Chakaria has a population of 474,321 [25, 26]. Males constituted 51.87% of the population, and females 48.13%. Adult literacy rate is 47.8%. Per capital income in the study area is 57.73 USD. In land communication strength in Chakaria is 180.71 km. The total amount of agricultural land is 27,141 hectors. Distance from the main land of Chakaria Upazila is 50 km [27]. Fig. 1 shows the location of the study area.

Fig. 1. Location of Chakaria island.

3. Mini-grid and HOMER software

A mini grid, also sometimes referred to as a "micro grid or isolated grid", can be defined as a set of electricity generators and possibly energy storage systems interconnected to a distribution network that supplies electricity to a localized group of customers. They involve small-scale electricity generation (10 kW to 10 MW) which serves a limited number of consumers via a distribution grid that can operate in isolation from national electricity transmission networks. The autonomous operation of mini-grid without connected to the centralized grid is a unique feature. Hybrid mini-grid systems often incorporate a 75-99% renewable supply. Conversely as the cost of fossil fuel increases, mini-grid systems are becoming more economically attractive as the cost of renewable energy resources decrease [28]. The HOMER (Hybrid Optimization of Multiple Energy Resources) micro grid software navigates the complexities of building cost effective and reliable micro grids that combine traditionally generated and renewable power, storage, and load management. HOMER is the global standard in micro-grid software, based on decades of listening to the needs of users around the world with experience in designing and deploying micro-grids and distributed power systems that can include a combination of renewable power sources, storage, and fossil-based generation (either through a local generator or a power grid). It is the world's leading micro grid modelling software. It was developed by the National Renewable Energy Lab (NREL), a division of the U.S. Department of Energy [29].

4. Electricity demand in Chakaria

Based on data obtained from Ref. [27], the electrical load data of Chakaria is imported in the software with 10% day to day and 20% time step random variability. The electrical load in a year with random variability is presented in Fig. 2. Annual average electricity demand of this island is 89,640 kWh/day. The yearly average load is 3,735 kW and load factor is 0.51. Peak load 7,333 kW is found in month of August.

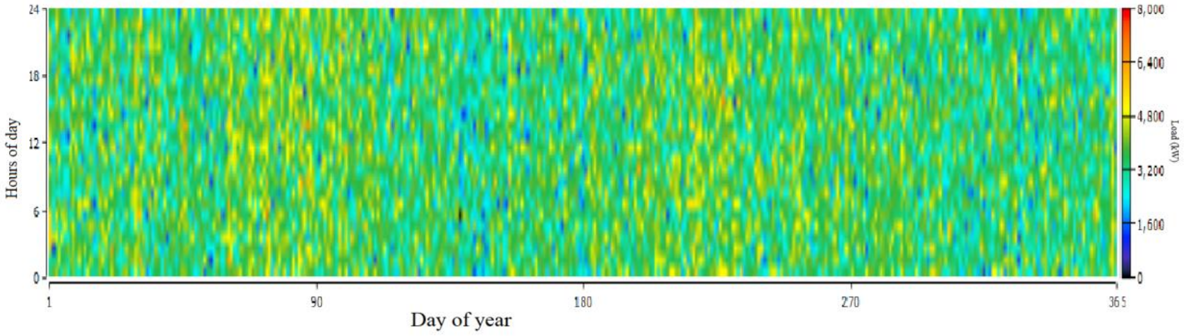

Fig. 2. Electrical load profile of Chakaria Island in kW.

5. Renewable energy resources in Chakaria

Chakaria Island is furnished with renewable energy resources mainly solar and wind energy. The potentialities and feasibilities of these available energy resources are described below. The monthly average wind speed data in this island, fluctuated from 2.83 m/s to 5.11 m/s at 50 meters above the surface of the earth, is imported in this software from NASA Surface meteorology and solar energy database. Maximum wind speed of 5.11 m/s is found in June. Studies have found that average wind speeds in a particular location need to exceed at least 6–8 m/s for a small wind turbine to be economically viable [30]. It is not feasible to operate a wind turbine proficiently and parsimoniously, as the average wind speed in Chakaria over a year is only 3.65 m/s, which is quite low.

Solar Global Horizontal Irradiance (GHI) data is taken from National Renewable Energy Lab database. Fig. 3 shows the solar radiation data used in the simulations in which the left vertical axis represents the daily radiation data while the right one represents the clearness index. The solar GHI in Chakaria is between 3.828 kWh/m^2/day and 5.979 kWh/m^2/day. The annual average solar radiation is 4.81 kWh/m^2/day. Solar GHI is high (above the average) from February to May (summer season), with a peak in the month of April, while solar irradiance is low in July, August, and September due to rainy season.

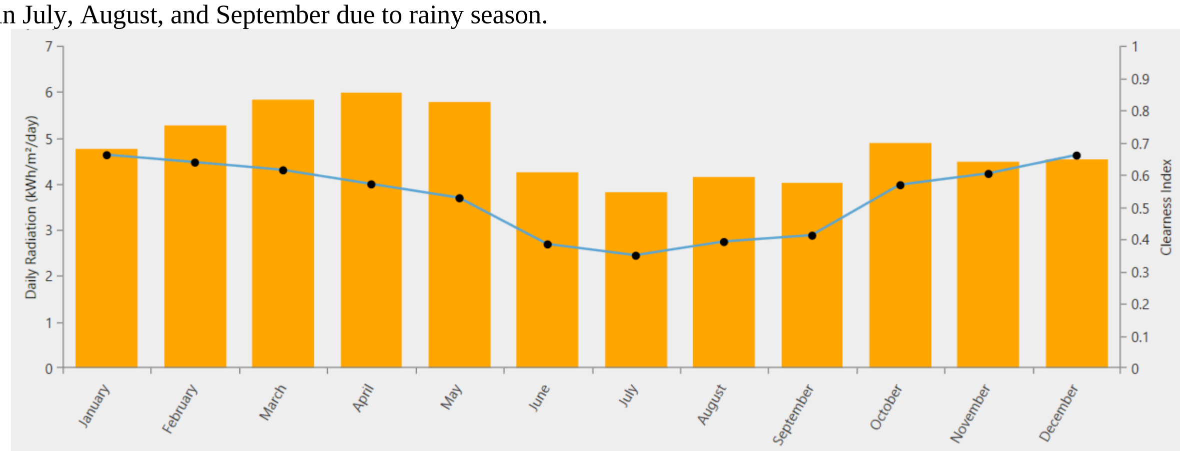

Fig. 3. Monthly average solar global horizontal irradiance (National Renewable Energy Lab database).

6. Proposed system

The proposed system consists of PV panels, Converters, and Batteries. This power generation system is designed for 25 years lifetime. The life span of PV panels, batteries and converter are considered as 25, 10, and 15 years respectively. The optimum size of all the components is determined by HOMER optimizer. Highly efficient Generic flat plate PV has been used in this simulation. Apart from, Powerwall 2.0; TESLA battery and S&C PureWave SMS-250 converter have been used in this experiment. Fig. 4 shows the schematic diagram of the proposed hybrid system. In this system, battery bank and PV panels are connected to the DC bus. Converter is placed between AC and DC bus. Load is connected to the system through AC bus. The sizes of each component are shown in Table 1.

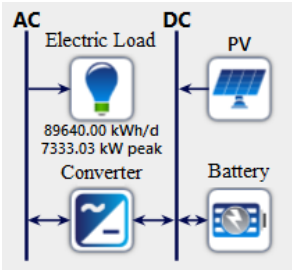

Fig. 4. Diagram of power generation system.

Table 1. System architecture.

Device	Size
Flat plate PV	135,605 kW
Li-ion battery	111,294 kWh
Converter	7,540 kW

7. Simulation results and analysis

Results of simulation are divided into electrical analysis, economic analysis and environmental impact which are described in the following articles.

7.1 Electrical analysis

Electrical analysis includes the simulation results and analysis of PV panel output, competitive electric production, renewable energy fraction, and performance of battery and converter. Table 2 represents energy production by different components, consumption, and excess electricity.

Table 2. Comparative production and consumption.

Components	Energy/year (kWh/year)	Percentage (%)
PV output	236,487,269	100
Total production	236,487,269	100
Average demand	32,698,370	-
Excess energy	200,840,158	84.9

7.1.1 PV output

Flat plate PV panel is considered in this proposed system to harness solar energy. Efficiency at standard test conditions is 13% and nominal operating cell temperature is 47^0. By using Homer optimizer, the size of flat plate PV panel is found 135,605 kW. PV panels produce 236,487,269 kWh/year and 647,910 kWh/day, and its capacity factor is 19.9%. Annual power output of PV panel is shown in Fig. 5. Maximum and mean output is 119,279 kW and 26,996 kW respectively. Hours of operation in one year is 4,371 and PV penetration is 723%. Levelized cost is 0.0165 \$/kWh. HOMER uses the following equation to calculate the output (P_{pv}) of the PV array.

$$P_{PV} = Y_{PV} f_{PV} \left(\frac{\overline{G}_T}{\overline{G}_{T,STC}} \right) \left[1 + \alpha_P \left(T_C - T_{C,STC} \right) \right] \qquad (1)$$

Here, Y_{PV} is the rated capacity of the PV array under standard test conditions (kW), f_{PV} is the PV radiating factor (%), $\overline{G}_T$ is the solar radiation incident on the PV array in the current time step (kW/m^2), $\overline{G_{T,STC}}$ is the incident radiation at standard test conditions (1 kW/m), α_P is the temperature coefficient of power (%/°C), T_C is the PV cell temperature in the current time step (°C), $T_{C,STC}$ is the PV cell temperature under standard test conditions (25^0C).

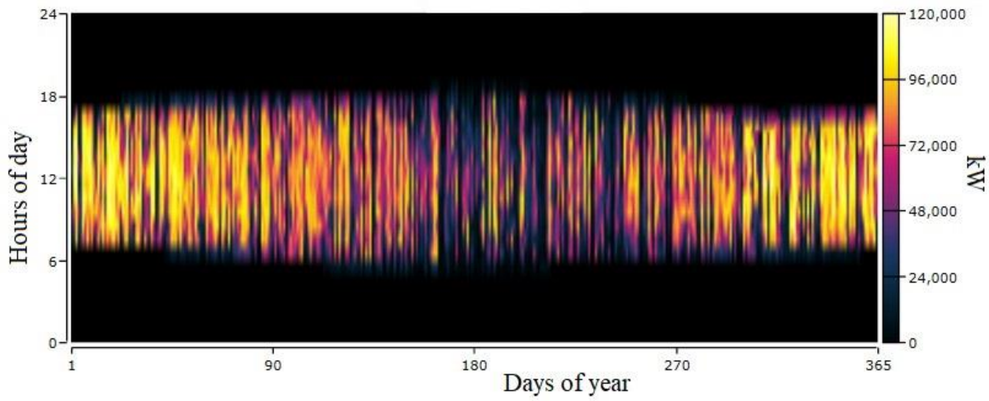

Fig. 5. Annual power output by PV panels.

7.1.2 Performance of battery and converter

Batteries are used to store excess electricity and utilized this energy during shortage. Annual throughput of 111,294 kWh Li-ion batteries is 18,356,566 kWh/year and expected life time is 10 years. Minimum state of charge is set to 40% and bus voltage is 220 V. State of charge of the batteries used in the proposed system is shown in Fig. 6 throughout the year with hours of the day. Average energy cost of the batteries is 0.0195 $/kWh. The input and output energies of the batteries are 19,427,871 kWh/year and 17,317,549 kWh/year respectively.

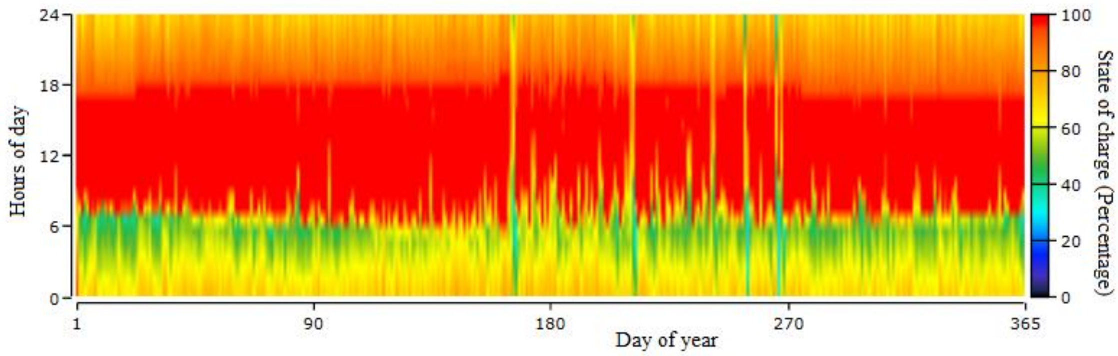

Fig. 6. State of charge of battery in a year.

A converter is used in this proposed project to convert DC power to AC as all loads are AC type. Size of converter is 7,540 kW with capacity factor 49.5%. Maximum and mean output is found 7,333 kW and 3,733 kW respectively. The converter output in a year is shown in Fig. 7. Hours of operation in one year is 8,756. Input and output energies of the converter in one year are 33,536,789 kWh and 32,698,370 kWh respectively. The relative capacity and efficiency of the converter are 100% and 97.50% correspondingly.

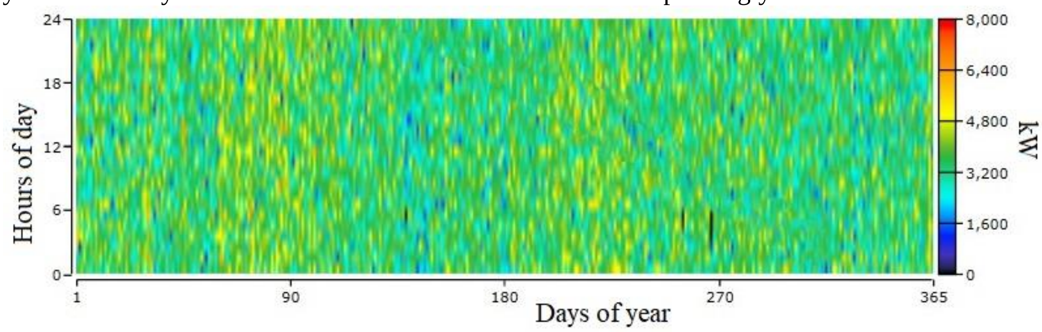

Fig. 7. Converter output in a year.

7.1.3 Electrical production

Monthly average electricity produces by the system is shown in Fig. 8. The amount of total electricity production in one year is 236,487,269 kWh. Total amount of electricity is produced by PV panels which is shown in Fig. 8. So, renewable energy fraction is 100%. Since, the amount of total primary load is 32,698,370 kWh/year thus the excess electricity is 84.9% of total generation.

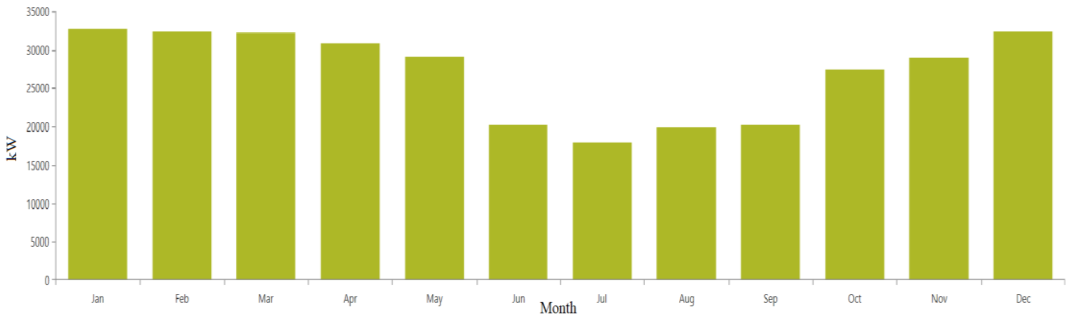

Fig. 8. Monthly average electricity production by PV panel.

7.2 Economic analysis

Project life time is expected as 25 years. Cash flow in 25 years by cost type is presented in Fig. 9. Different types of costs like replacement cost, salvage cost, operating cost, and capital cost are shown in Fig. 9. On the other hand, net present cost by component is presented in Table 3. From this simulation, the operating and net present cost is 5,448,328 $/year and 205,581,600 $/year respectively and cost of electricity is found 0.3362 $/kWh. This indicates a feasible system. HOMER finds the optimal system by determining the lowest possible initial capital costs, operating costs, net present costs, and cost of per unit electricity.

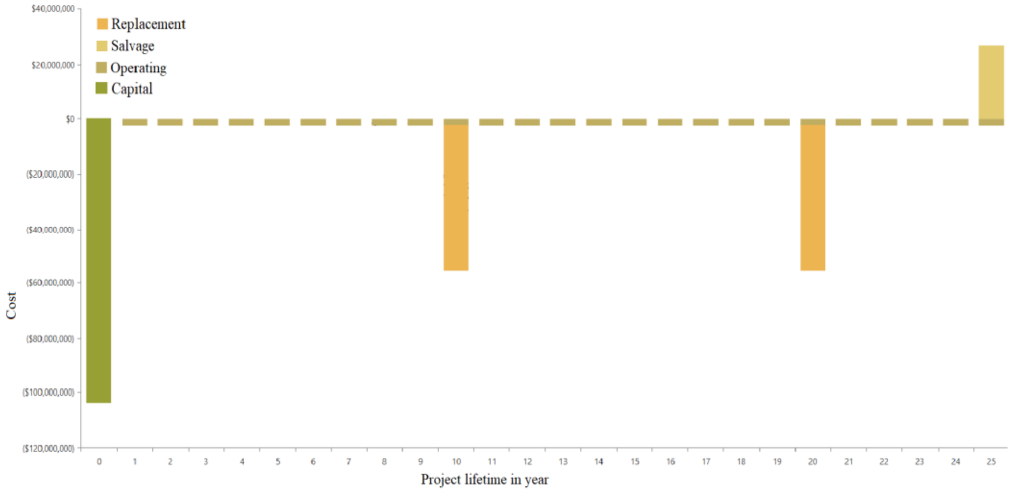

Fig. 9. Cash flow in 25 years by cost type.

Table 3. Net Present Costs by components.

Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
PV	47,461,895.19	0.00	25,360,986.67	0.00	0.00	72,822,881.86
Battery	53,586,000.00	75,942,134.34	0.00	0.00	14,918,973.68	114,609,160.66
Converter	2,638,873.41	0.00	15,510,732.65	0.00	0.00	18,149,606.06
System	103,686,768.60	75,942,134.34	40,871,719.31	0.00	14,918,973.68	205,581,648.58

7.3 Environmental impact

Since, renewable energy fraction in this system is 100%, thus the amount of fuel consumption is zero and no emission is produced. So, it is more environment friendly power generation system.

8. Conclusion

Renewable energy based power generation systems are attractive, cost competitive, and a common solution of energy demand in remote off-grid areas. To meet ever increasing per capita electricity demand of Bangladesh, integration of renewable energy technology is essential. In order to utilize renewable energy resources efficiently and economically with a reliable conventional energy source, an optimal mini-grid solar power generation system is developed with the help of HOMER ENERGY software. This proposed system can be a perfect long term solution to meet the energy demand in many remote localities like Chakaria Island. Cost of electricity found from this simulation is 0.3362 $/kWh which is acceptable. Performance of different components in this system, electrical demand, emissions, and economic aspects are also analyzed in this simulation.

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