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# Off-Grid Hybrid Energy System Incorporating Renewable Energy: The Case of Remote Coastal Area of Bangladesh

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*One of the major obstacles for economic development of Bangladesh is power crisis. A reliable, affordable and secure supply of energy is important for economic development. Shortage of electric power generation causes a significant amount of load shading every day. Scarcity of fossil fuel reservation is a worldwide problem. Moreover, fossil fuel based energy system has adverse effect on environment. Again, only one renewable energy based energy system is not economical. A renewable hybrid energy system may be used to reduce dependency on either conventional fossil fuel energy or only renewable energy system as well as has an excellent solution for electrification of remote areas where the grid extension is difficult and not economical. Abundance of renewable energy sources in the form of solar energy, wind energy provides opportunities of renewable energy based hybrid energy system in the coastal areas of Bangladesh. Wind energy or solar energy based energy systems are extensively studied and in operation in several remote areas of Bangladesh. But hybrid renewable energy studied has got little attention in Bangladesh. This research work is an in-depth scenario and analysis of the renewable hybrid energy in Feni, a remote coastal district of Bangladesh. Comparative study is also done with diesel based, solar energy based and wind energy based energy system. Optimization of hybrid renewable energy systems looks into the process of selecting the best components and its sizing with appropriate operation strategy to provide cheap, efficient, reliable and cost effective alternative energy. This paper analyzes all the conditions and constraints of the renewable energy integrated hybrid system and proposes an optimal combination of energy components for coastal area with minimizing the life cycle cost. In this analysis, it is found that for a 19MW power plant in Feni the cost of energy for solar based, wind based, diesel based and hybrid solar-wind-diesel based power plant are 0.39$/KWh, 0.258$/KWh, 0.218$/KWh and 0.157$/KWh, respectively. Energy generation by hybrid system reduces the generation cost and helps in balancing the cost of energy. Again a standalone renewable energy incorporated hybrid energy system will reduce load demand from the grid and will be an eco-friendly energy system.*

**Field of Research:** Electrical Engineering (Renewable Energy)

## 1. Introduction

Electricity access rate and utilization of energy are the indicators economic growth of a country. Densely populated Bangladesh has a population of almost 160 million people with electricity access rate of about 50%. Presently electricity demand growth is about 10%. At this moment power demand in Bangladesh is about 7500MW,

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whereas the generation ranges only 5000-6000MW. Demand is estimated to exceed 10,000 MW by 2015. As there is huge difference between generation and demand of electricity, people of Bangladesh is experiencing a significant amount of load shading. All the power generation plant relies on fossil fuels for its energy especially on gas resources. Natural gas is used as fuel for 76% of the energy generation. But it's a matter of fact that the present proven reserve would be used up by a decade. Bangladesh has sufficient high quality coal resources. But the coal mining is at its initial stage. There are uncertainties in the exploration of gas and coal. Another important concern is that fossil fuel based power plant is not environment friendly. The lack of energy resources can be met by renewable energy which is abundant in nature. Renewable energy is also considered as green or clean energy. Renewable energy resources like solar, wind, hydro and tidal could be utilized in some areas of Bangladesh to establish renewable energy based power generation stations. The coastal area in the southern part of Bangladesh has a huge potential of establishing solar and wind power generation. Feni is a small southern district of Bangladesh. The annual average wind speed is 6.51 m/s at 50m height which is sufficient to harness wind energy and the annual average solar irradiation, which is 4.52 $kWh/m^2/day$, is suitable for setting up solar energy system. Bangladesh government and several other non-government organizations have been working on setting up single renewable resource based energy system. Renewable hybrid energy system is yet to be introduced. Off grid hybrid renewable energy system is the most efficient and reliable energy source than the energy source which based on single renewable energy such as Solar, Wind or conventional energy source. It reduces the load demand on grid and save fuel as well as natural resources. It is also economical and eco friendly which contribute in balancing of environment.

Around the world, effort is being made to study the viability of renewable energy incorporated hybrid system as alternative of diesel generator. In this work a design of off-grid solar-wind-diesel hybrid power system for Feni of Bangladesh is presented. Firstly, the hybrid energy system that has been established all over the world is reviewed. Then methodology of analysis of this work is described in details. The data of energy resource collected from various reliable sources are presented here. The energy resource data analysis procedure is discussed. Then the designed hybrid energy systems are provided. After that selection process of the efficient components which are used in the hybrid system are described. Detailed economic analysis of the proposed system is also carried out to validate the design and presented here. Optimal design of energy systems based on solar energy, wind energy and diesel fuel are also done here. Comparative study shows renewable hybrid system is the most cost effective. Analysis of hybrid energy system for Bangladesh like this work has not reported yet. From this work, the proposed hybrid system shows tremendous prospect in Bangladesh.

## 2. Literature Review

Hybrid renewable energy study has become popular in the recent time because it offers an effective alternative way of solution of energy crisis. Hybrid wind-diesel systems are an interesting solution for the electrification of isolated consumers presenting a significant cost advantage in relation either to a diesel-only or to a wind-based stand-alone system (Kaldellis, Kondili & Filios, 2006). Micro-hydro-wind systems are found to be the optimal combination for the electrification of the rural

villages in Western Ghats (Kerala) India, based on the case study by Askok (2007). Hybrid energy system with incorporation of renewable energy system helps improve load factors and assist on maintenance and replacement costs as the energy sources can harmonize each other (Paska, Biczel & Kłos, 2009). However to construct an optimized hybrid energy system, evaluation of the suitable type of and size of renewable energy system is essential. Effort is being made to study the viability of renewable energy incorporated hybrid system as alternative of diesel generator (Ekren & Ekren, 2008). Studies of Karki & Billinton (2004), Liu & Islam (2006), Billinton & Bai (2004) show that wind-diesel hybrid power systems considerably reduce the need for storage of fuel, fuel consumption cost, and greenhouse gas emission. Performance analysis of hybrid system has been carried out by several researchers (Elhadidy, 2002). Optimization of sizing of different hybrid system has been investigated (Yang, Lu & Zhou 2007), (Boroy & Salameh,1994), (Lal, Dash & Akella, 2011). This paper presents a design of off-grid solar-wind-diesel hybrid power system for Feni of Bangladesh.

## 3. Data and Methodology

An optimal design of an off-grid renewable hybrid system is proposed for Feni, a coastal area of Bangladesh. This system design can be applied to other coastal areas and also some remote areas of Bangladesh. Solar based, wind based and diesel based optimized energy system is also designed. Firstly, Energy resources are analyzed to find out the most suitable energy resources for planning a energy system. Then using the best suitable energy resources a energy system is designed. The simulation software HOMER (Hybrid Optimization Model for Electric Renewables) is engaged for the optimal planning of sizing of different components of the system. Considering each system configuration HOMER performs the energy balance calculations. The system cost calculations are done studied which account costs such as capital, replacement, operation and maintenance, fuel, and interest. This economic analysis is carried out to determine the feasibility of the proposed system. Comparisons with solar photovoltaic (PV) based energy systems, wind based energy system and diesel based energy system are studied for confirming the practicability of the proposed system.

### 3.1 Energy Resources

Energy resources selection is crucial for a suitability energy system design. In the location of our study, wind energy and solar energy are enough for harvesting these renewable energy for power generation. As gas reserve may perish within a decade, diesel is used as the fuel for power generation from fossil fuel.

#### 3.1.1 Solar Energy Resources in Feni

In photovoltaic system solar cells or panels are used to convert sunlight directly into electricity. The monthly averaged global radiation data has been taken from NASA (National Aeronautics and Space Administration) and clearness index is a measure of the clearness of the atmosphere, has an average value of 0.489 for Feni. Table 1 provides the data of clearness index and daily radiation for Feni.

**Table 1: Solar Irradiation in Feni**

| Month | Clearness Index | Daily Radiation (kWh/m$^2$/day) |
|---|---|---|
| January | 0.656 | 4.610 |
| February | 0.612 | 4.950 |
| March | 0.557 | 5.240 |
| April | 0.565 | 5.910 |
| May | 0.455 | 5.000 |
| June | 0.342 | 3.810 |
| July | 0.362 | 4.000 |
| August | 0.371 | 3.940 |
| September | 0.397 | 3.860 |
| October | 0.500 | 4.230 |
| November | 0.611 | 4.430 |
| December | 0.642 | 4.280 |
| Annual Average | 0.489 | 4.518 |

### 3.1.2 Analysis of Wind Data in Feni

Feni is situated at coastal line along the Bay of Bengal. According to the studies of Bangladesh Meteorological Department (BMD), wind speed is high in Bangladesh during the Monsoon (7 months, March–September). In rest of the months (October – February) wind speed remains either calm or too low. The peak wind speed occurs during the month of April and May. The wind speed data at Feni is recorded at 50 m height. Table.1 shows the monthly average wind speed around the year at Feni.

**Table 2: Wind Speed at 50 M Height in Feni**

| Month | Wind Speed (m/s) |
|---|---|
| January | 5.100 |
| February | 5.300 |
| March | 7.000 |
| April | 7.700 |
| May | 8.100 |
| June | 7.200 |
| July | 7.400 |
| August | 6.800 |
| September | 6.700 |
| October | 6.200 |
| November | 5.600 |
| December | 4.900 |
| Annual Average | 6.742 |

Wind energy is the kinetic energy of the moving air mass. Total available power calculated by equation (1) can be extracted and is given by,

$$P = \tfrac{1}{2}.\rho.AV^3.C_p \quad (1)$$

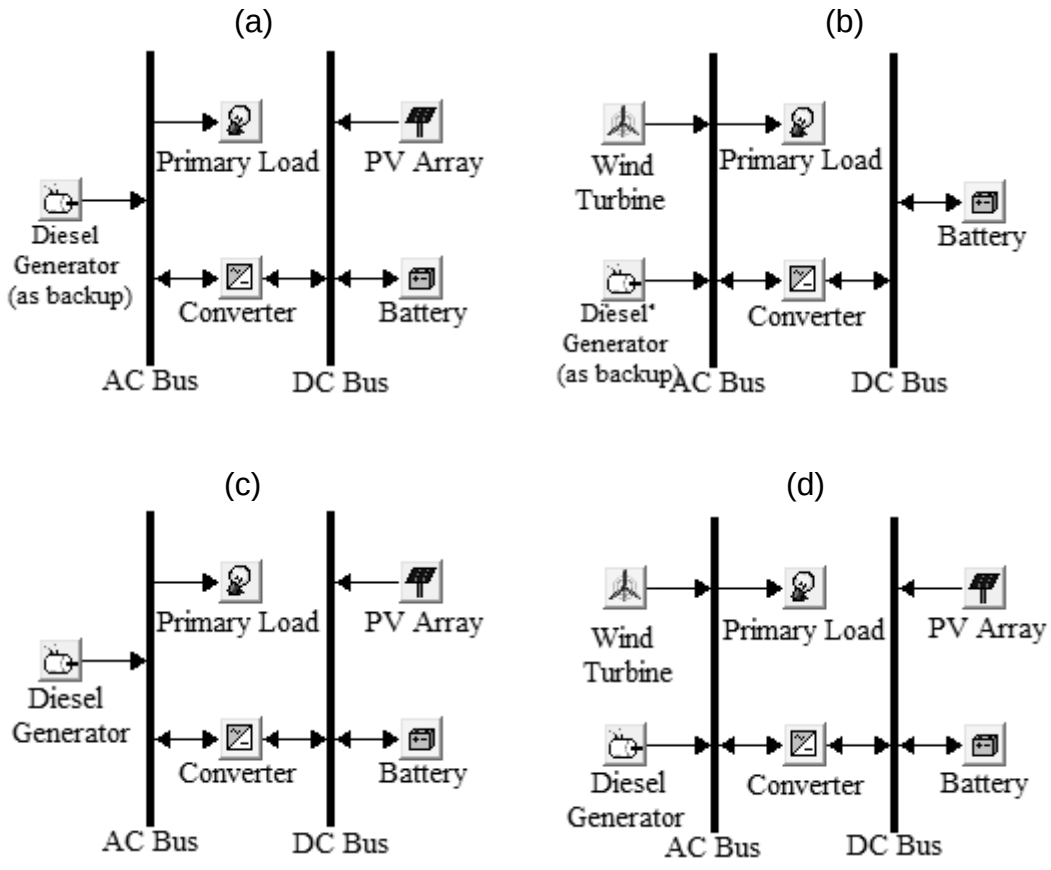
$C_p$ is the power coefficient (Alam, 2001) is the ratio of power extracted by a wind turbine to power available in wind at that location. A theoretical maximum of 59.3% of available power can be extracted. Practically a typical maximum of 40% is achievable.

The Weibull value, k is a measure of distribution of wind speed over the year. It is taken as 1.64 (Mukut, Islam & Alam 2008) as Sandwip is near to Feni. The autocorrelation factor measures the randomness of the wind. The autocorrelation factor value is taken as 0.85 indicating wind pattern is not random. The diurnal pattern strength is the measure of how strongly the wind speed depends on the time of the day. In this study, 0.25 is used. 15 hours are used as the hour of peak wind speed.

### 3.2 Design of Hybrid Energy System

Energy system for Feni is designed where diesel generator has been combined with wind and solar power generation as backup generator. Diesel generator has been chosen for its operating feasibility, low cost, quick start and small size. It has good thermal and electrical efficiency. Diesel based hybrid energy system is also designed. But only diesel generator is not cost effective to meet the current electrical demand. A solar-wind-diesel hybrid system can be a cost effective solution. Figure 1 show the diagram of the different planned energy system.

**Figure 1: Single Line Diagrams of (a) Solar Energy System, (b) Wind Energy System, (c)Diesel Based Hybrid Energy System, and (d) Renewable Hybrid (Solar-Wind-Diesel) Energy System**

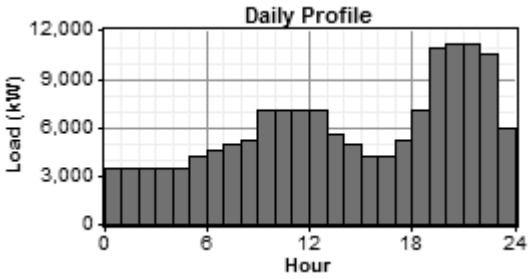


### 3.2.1 Electricity Demand Profile

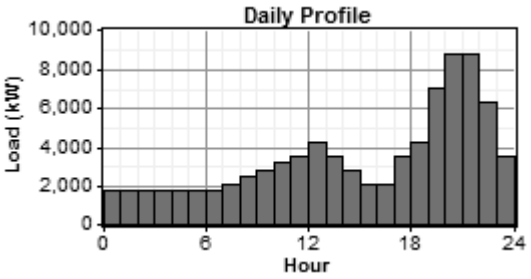
Per capita power consumption is assumed about 300 kWhr per annum for analyzing the electrical demand for Feni after doing necessary survey. According to annual report of Bangladesh Power Development Board (BPDB), per capita power generation is 212 kWhr. The daily load profile for summer season is as shown in the figure 2(a). The daily load profile on a day of winter season is assumed as shown in figure 2(b). Randomness of the daily consumption is taken as 15%. And variability of hour to hour is considered as 20%. Energy demand per day is 120.426 MWhr and annual Peak load is taken 19.319 MW taking all factors in consideration.

**Figure 2: Load Profile of a Day (a) in Summer Season, and (b) in Winter Season**

(a)




(b)




### 3.2.2 System Components

For the above mentioned four energy system design, various components are taken in consideration. Description and suitability of the components are discussed here. Average wind velocity at 50m height is 6.742 m/s in Feni. But at winter, wind velocity goes below the average wind velocity. Enercon E33 wind turbine is a suitable choice for low wind speed as its cut-in speed is 3 m/s. It has a rated capacity of 330 kW. The installation cost for Enercon E33 (50 m height tower) is $ 500000.

The cost of PV module including installation has been considered as $ 7278. Life time of the modules has been taken as 25 years. 6.9 kW PV modules, Sunmodule SW 230 POLY V2.0 PALLET, are considered. PV modules output is DC and is connected to DC bus. For all the system, Surrette 6CS25P battery with energy storage capacity of 6.94 kWhr, is used for design of the hybrid system. Converter is used to convert from AC to DC and DC to AC. Inverter efficiency is taken 90% and rectifier efficiency is considered 85%.

Diesel generators operate in parallel with the wind turbine and solar energy system to increase the maintenance flexibility, efficiency and distribute the electric load more optimally. Capital cost for per MW of diesel generator is considered $ 180000.

### 3.2.3 Economics and Constraints

The energy system that is designed in this work has assumed to have 25 years. Annual interest rate is considered 10%. For the renewable hybrid energy system the constraint that is applied is 50% of the load should be from the renewable energy.

## 4. Results and Discussion

Simulation software HOMER is used for optimal planning and simulation of the hybrid system. After optimal planning the design components size is measured. The system components and their size for optimal design are shown in table 3. Figure 3, 4, 5 and 5 show the contribution from different source in the power supply. In the most optimal system among the four systems, Solar PV energy supplies 17% of load demand, wind energy contribute 49% of demand and rest demand is fulfilled from diesel generator.

**Table 3: Optimum System Architecture of Energy System**

| System Component | Solar Energy System | Wind Energy System | Diesel Based Energy System | Hybrid Renewable Energy System |
|---|---|---|---|---|
| | Size | Size | Size | Size |
| PV | 95,000 kW | - | 2,000 kW | 5000 kW |
| Wind Turbine | - | 49,500 kW | - | 9900 kW |
| Diesel Generator | 2,400 kW | 7,000 kW | 20,000 kW | 10000 kW |
| Battery | 24,000 unit | 8,100 unit | 4,500 unit | 4500 unit |
| Converter | 12,000 kW | 5,000 kW | 2,000 kW | 4500 kW |

**Figure 3: Monthly Average Electricity Production of Solar Energy System**

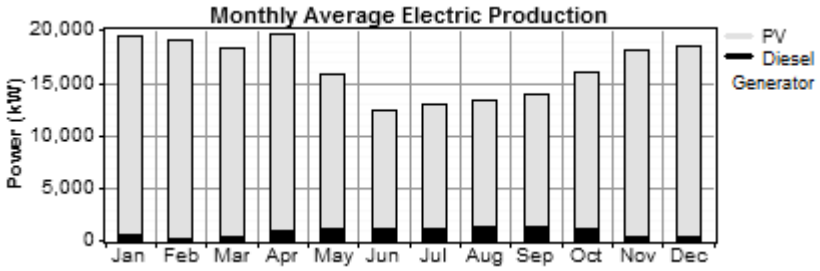



**Figure 4: Monthly Average Electricity Production of Wind Energy System**

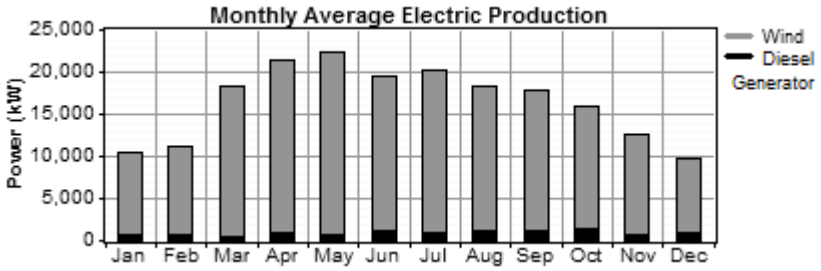


**Figure 5: Monthly Average Electricity Production of Diesel Based System**

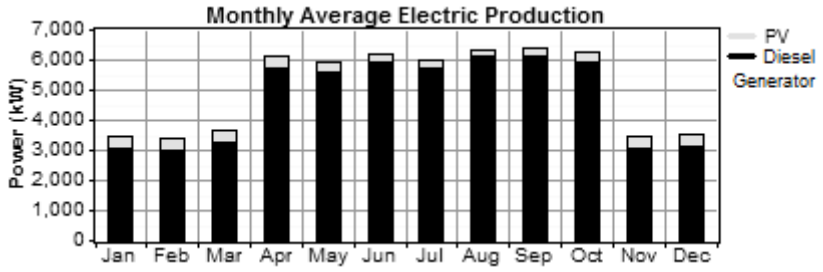
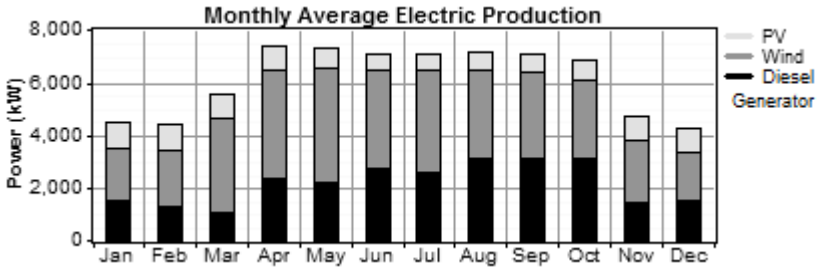



**Figure 6: Monthly Average Electricity Production of Solar-Wind-Diesel Hybrid System**




### 4.1 Economic Analysis

The system is analyzed in HOMER according to the cost of electricity (COE) of the system. Other factors which influence the analysis are capital cost, operating cost, renewable energy factor, total Net present cost (NPC) and diesel consumption rate. Table 4, 5, 6 and 7 show the capital cost, replacement cost, operation and maintenance cost and Fuel cost of different system components of the system.

**Table 4: Net Annualized Cost of the Optimum Solar System**

| System Component | Capital cost ($) | Replacement Cost ($) | Operation & Maintenance Cost ($) | Fuel Cost ($) | Total Cost ($) |
|---|---|---|---|---|---|
| PV | 11,039,320 | 0 | 13,768 | 0 | 11,053,088 |
| Diesel Generator | 47,593 | 0 | 7,732 | 1,375,541 | 1,430,211 |
| Battery | 2,644,034 | 626,076 | 24,000 | 0 | 3,205,475 |
| Converter | 125,592 | 0 | 120,000 | 0 | 245,592 |
| Others | 881 | 0 | 500 | 0 | 1,381 |

**Table 5: Net Annualized Cost of the Optimum Wind System**

| System Component | Capital cost ($) | Replacement Cost ($) | Operation & Maintenance Cost ($) | Fuel Cost ($) | Total Cost ($) |
|---|---|---|---|---|---|
| Wind Turbine | 8,262,606 | 0 | 90,000 | 0 | 8,352,603 |
| Diesel Generator | 138,812 | 0 | 9,033 | 1,470,332 | 1,613,147 |
| Battery | 892,361 | 190,545 | 8,100 | 0 | 1,054,252 |
| Converter | 52,330 | 0 | 50,000 | 0 | 102,330 |
| Others | 881 | 0 | 500 | 0 | 1,381 |

**Table 6: Net Annualized Cost of the Optimum Diesel System**

| System Component | Capital cost ($) | Replacement Cost ($) | Operation & Maintenance Cost ($) | Fuel Cost ($) | Total Cost ($) |
|---|---|---|---|---|---|
| PV | 232,407 | 0 | 290 | 0 | 232,697 |
| Diesel Generator | 396,605 | 0 | 86,070 | 8,239,937 | 8,722,165 |
| Battery | 495,756 | 104,148 | 4,500 | 0 | 583,432 |
| Converter | 20,932 | 0 | 20,000 | 0 | 40,932 |
| Others | 881 | 0 | 500 | 0 | 1,381 |

**Table 7: Net Annualized Cost of the Optimum Solar-Wind-Diesel Hybrid System**

| System Component | Capital cost ($) | Replacement Cost ($) | Operation & Maintenance Cost ($) | Fuel Cost ($) | Total Cost ($) |
|---|---|---|---|---|---|
| PV | 581,017 | 0 | 725 | 0 | 581,742 |
| Wind Turbine | 1,652,521 | 0 | 18,000 | 0 | 1,670,521 |
| Diesel Generator | 198,303 | 0 | 26,985 | 3,622,708 | 3,844,062 |
| Battery | 495,756 | 104,148 | 4,500 | 0 | 583,432 |
| Converter | 47,097 | 0 | 45,000 | 0 | 92,097 |
| Others | 881 | 0 | 500 | 0 | 1,381 |

The solar energy system has a net present cost of $ 144,649,408. The operating cost per year is $ 2,078,328. Cost of energy is found $ 0.392/kWhr. Total load that is supplied by the system is 40,642,484kWhr per year. The wind energy system has a net present cost of $ 100,970,432. The operating cost per year is $ 1,776,727. Cost of energy is found $ 0.258/kWhr. Total load that is supplied by the system is 43,172,168kWhr per year. The diesel energy system has a net present cost of $ 86,963,568. The operating cost per year is $ 8,434,028. Cost of energy is found $ 0.218/kWhr. Total load that is supplied by the system is 43,955,468kWhr per year.

The renewable hybrid energy (solar-wind-diesel) system has a net present cost of $ 61,480,932. The operating cost per year is $ 3,797,661. Cost of energy is found $ 0.157/kWhr. Total load that is supplied by the system is 43,263,960kWhr per year.

### 4.2 Comparative Study

Table 8 shows a comparative study of proposed energy system with other energy system for Feni. The simulation results clearly reveal that solar-wind-diesel hybrid system is the most cost effective off grid power system.

**Table 8: Cost Comparison with Other Energy System**

| Energy System | Net Present Cost ($) | Fuel Cost ($) | Cost of Energy ($/kWhr) |
|---|---|---|---|
| Solar-Wind-Diesel | 61,480,932 | 34,892,704 | 0.157 |
| Wind | 100,970,432 | 0 | 0.258 |
| Solar | 144,649,408 | 0 | 0.392 |
| Diesel | 86,963,552 | 79,171,440 | 0.218 |

### 4.3 Environmental Effects

The proposed Solar-wind-diesel hybrid system reduces gas emission by a significant amount due to reduced fuel consumption. In this system carbon dioxide emission rate is 14,029,089 kg/yr, carbon monoxide emission rate is 34,629 kg/yr and sulfer dioxide emission rate is 28,173 kg/yr. The emission for this system has been decreased by 69 percent from the diesel based energy system.

## 5. Conclusion

Electricity is now one of the basic needs of human. Severe scarcity of power in Bangladesh has become a threat to the economical development. In future, the supply of fossil fuel will end but renewable energy such as wind, solar, water will never ending source of energy. The drawback of the renewable energy sources is they are location specific. For instance solar energy can be used only where there is good exposure of sunlight, similarly electricity from wind energy can be generate where there is ample amount of air and so on. But Fossil fuels are devastating for environment but renewable energy is not harmful for environment in any way. The importance of renewable energy thus becomes paramount. Again only one renewable energy based system cannot supply entire load demand and this type of system is also economically less practical. From this work this can be concluded that off-grid solar-wind-diesel hybrid energy system can be cost effective solution for the coastal regions of Bangladesh where renewable energy resources are abundant. It also will lessen demands on grid. Moreover this hybrid system reduces the emission of gases harmful for ecological system and help to trim down the environmental

pollution. Once the technology is perfected, hybrid energy system with renewable energy sources will prove to be the most cost effective.

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