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Optimum Planning of Hybrid Energy System using HOMER for Rural Electrification

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ABSTRACT

A large proportion of the world's population lives in remote rural areas that are geographically isolated and sparsely populated. This paper discussed the efficient system of sustainable renewable energy for domestic use and its total cost for the off-grid area; taking *Sandip-para* as model which is in *Raujan upzila* of Chittagong district. Method of this paper is collecting the basic data of solar radiation, wind speed and other required input data, and then hybrid optimization. Simulation model was developed using the HOMER energy modeling software. Simulation model has been used to find out the best technically viable renewable based energy efficient system for different numbers of household. Results have been presented as the most efficient economic way for electrifying the area.

General Terms

Hybrid power system, Off-grid area.

Keywords

Hybrid optimization model of renewable energy (Homer), Sandip-para, Domestic and agricultural power consumption, Cost analysis, Payback.

1. INTRODUCTION

Hybrid systems compromises with two or more renewable energy sources for the generation of electrical power so that the deficit of power generation from one source can be easily compensated by the other source available in order to maintain the reliability of power supply. Comparatively the efficiency of the power generated from renewable sources are less than that of power generated from conventional resources, thus employing hybrid systems for renewable resources can be efficient and reliable solution for the generation of electrical power. It can be designed to achieve desired attributes at the lowest acceptable cost which can address limitations in terms of fuel flexibility, efficiency, reliability, emissions and/or economics. [1]

2. NECESSITY OF HYBRID SYSTEM:

Hybrid system is considered as one of the most efficient means to access electricity from locally available renewable energy resources where the access to national grid is quite impossible and also not economic. People of several places are out of reach of electricity also because of its geographical landscape and conditions where providing electricity from a centralized power plant through some sorts of transmission lines is not possible. The people residing in such kind of place can be highly benefitted by the means of hybrid system. Also depending upon conventional sources of energy is becoming harder day by day due to its rising prices and limited availability. Thus developing countries burdened by the high costs of imported fuel can benefit from small, sustainable renewable energy system that use a combination of a solar, wind and micro-hydro technologies to electrify rural, off-grids towns and villages. In addition to facilitating livelihood development and reducing fossil fuel dependence "Hybrid" system aids the development of carbon credits and funding options to subsidize clean renewable energy projects. [2-4]

3. SUMMARY OF THE PROJECT SITE

The name of the project site is *Sandip-para* which lies in *Raujan Upazila* of Chittagong district. (Latitude: 22.354265, Longitude: 91.838051).It's one of the non grid-connected areas of Bangladesh and about 30 families live here. It is surrounded by hilly areas and most of the people living here are dependent upon agriculture for their livelihood.

Fig. 1: *Sandip-para* – a top view from Google Earth. [5]

The people of this region experience the continuous daylight throughout the year although the solar radiation of winter season remains comparatively low than that of summer season. The average solar insolation intensities of about 4.758kWh/day with average sunshine hour of 5.8hours/day of about 300 days of sun a year is available in this region. The wind speed of this area is quiet low; mostly below the optimum level (4 m/s). But during the months May-July it gets a favorable wind speed (max 4.3m/s) [6]; for some low power generation but enough to meet the demand of irrigation system during that dry season. It will reduce the overall cost for electricity generation for this particular area. So combining both solar energy and the wind energy to produce power, it's possible to meet the current demand. Even though the potential of renewable sources are moderate, the application of renewable generators as standalone units will not be sufficient to provide a continuous power supply due to seasonal and non-linear variation of renewable resources. To ensure a balance and stable power output it needs to be integrated with a diesel generator. Here in our study we have developed a hybrid system for this area which consists all the load demands using Solar PV, Wind turbine and a Diesel Generator.[7]

4. LOAD ESTIMATION:

4.1 Loads (July-October)

Electricity demand for each family:

Two CFL bulb = 20(power rating of each bulb) ×2(no. of bulb) ×4(hours of operation) = 160Wh

One Fan = 60(power rating of fan) ×1(no. of fan) ×8(hours of operation) = 480Wh

One Television set (B&W) Or Radio set Or other appliances (e.g. Mobile Charger) = 40(average power rating) ×4(hours of operation) = 160Wh

Thus, from the above estimation, peak watt demand for each family (W_p) = 140W and total demand of each family per day = 800Wh/day

Electricity demand for a mosque:

Two CFL bulb = 20(power rating of each bulb)×2(no. of bulb)×4(hours of operation) = 160Wh

One Fan = 60(power rating of fan)×1(no. of fan)×4(hours of operation) = 240Wh

Peak Watt demand for the mosque (W_p) = 100W and total demand of mosque per day = 400Wh/day

Electricity demand for a school:

Four CFL bulb = 20(power rating of each bulb)×4(no. of bulb)×4(hours of operation) = 320Wh

Two Fan = 60(power rating of fan)×2(no. of fan)×4(hours of operation) = 480Wh

Peak Watt demand for the school (W_p) = 200W

Total demand of school per day = 800Wh/day

Here maximum demand of power = (140×30)+100+200 = 4500W = 4.5kW

Maximum demand of energy per day = (800×30)+400+800 = 25200Wh/day = 25.2kWh/day

Fig.2 is showing load duration curve for July-October

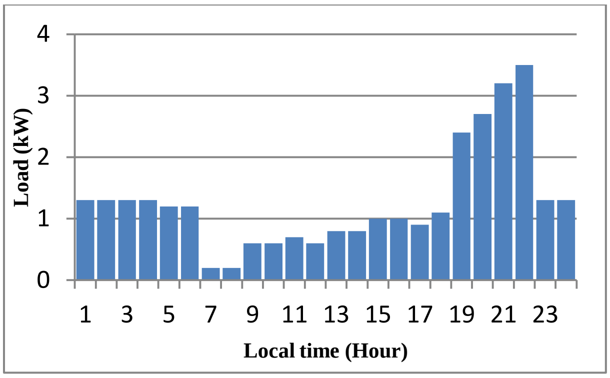

Fig. 2: Daily Load Profile (July-Oct)

4.2 Loads during dry season (March-June):

March-June is the irrigation period of the year. As an agro based area we have to make special consideration for load distribution during this period as the farmers will use pumps for irrigation purpose that consumes large amount of power. Considering the area of cultivating land in *Sandip-para* have selected 2 pump each of 1 H.P that is = 746Watts. [8]

Two pump =746(power rating of each pump) ×2(no. of motor) ×8(hours of operation) =11936 Wh/day.

Other loads will remain as same as the (July-October) period. A typical load duration curve clarifying the consumption of energy per hour of the day for a day in the months of March – June (Dry season) is shown in Fig 3

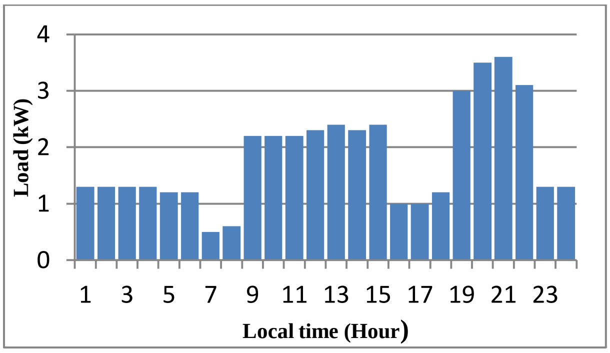

Fig.3: Daily Load Profile (March-June)

4.3 Loads during winter season (November-February)

This is the winter season so of the year, there will be no loads of fan. Almost all the other loads will remain same as July-October. Hence total Energy demand of the village is 10.08 kWh/day. Fig.4 is showing load duration curve for November-February.

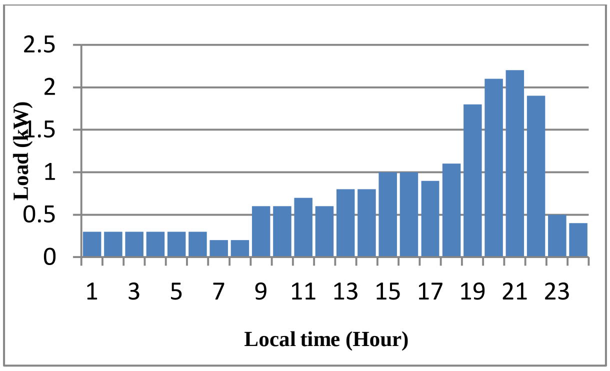

Fig. 4: Daily load profile (November-February)

5. COMPONENTS OF THE PROPOSED HYBRID SYSTEM:

Considering our project site we have designed our hybrid system with power source of Wind Energy, Solar insolation and diesel. Solar insolation is the most abundant green energy source here when necessary wind speed for power generation will only be available for 2-3 months. So a diesel generator is taken for continuous supply of power. Hence the components of our systems are:

1. Wind Turbine
2. Solar Photovoltaic system
3. Diesel Generator
4. Storage device

6. INPUT PARAMETERS

6.1 Wind Turbine scheme:

Wind speed varies throughout the year and the exact wind speed for a particular area in different seasons is not available. Fortunately for us our project site is near CUET and recently a study based on this area's wind speed is done by LGED (*Local Government Engineering Department)*.Although they have marked the area as low potential wind site but for low power generation considering a low populated site like *Sandip-para* it can be taken into consideration. The wind speed data for each month is given below in Table 1.

Table 1.Wind speed throughout the year [6]

Month	Wind speed (m/s)
January	1.3
February	2.1
March	2.1
April	2.8
May	2.5
June	4.3
July	2.8
August	2.6
September	1.9
October	1.4
November	1.2
December	1.1
Average	2.172

6.2 Solar PV scheme:

The solar resource input for the various months throughout the year was obtained from the internet via HOMER software by providing the latitude, longitude and time zone information as required by the software.

Location of the site:

Latitude 22^{0}28' North

Longitude: 91^{0}58' East

Time Zone: [GMT+06:00] Dhaka

The solar radiation data for various months throughout the year in *Sandip-Para* is shown in Table 2.

Table 2. Solar radiation throughout the year. [9]

Month	Clearness Index	Daily Radiation (kW/m^2/d)
January	0.646	4.597
February	0.628	5.126
March	0.596	5.634
April	0.550	5.760
May	0.527	5.786
June	0.390	5.786
July	0.368	4.335
August	0.398	4.048
September	0.418	4.224
October	0.555	4.083
November	0.601	4.725
December	0.649	4.409
Average	0.513	4.758

The solar radiation for each month was obtained where it was found that the maximum solar radiation was found for the month of May and June with daily radiation of 5.786kWh/m^2/day whereas the minimum radiation was found for the month of August with daily radiation 4.048kWh/m^2/day .The average radiation throughout the year was 4.758 kWh/m^2/day.

6.3 Diesel Generator:

For uninterruptable power supply we have used a 2kW diesel generator. Only for this scheme a traditional fossil fuel source (diesel) is used. When Wind-PV will unable to fulfill the load demand than the generator will operate. Some specifications of the diesel generator are:-

Limit consumption: 5000L/yr

Lower heating value: 43.2MJ/Kg

Density: 820KG/m^3

Carbon content: 88%

Sulphur content: 0.33%

At present the price of diesel: 61Tk/L (liter). [9]

6.4 Storage device:

The hybrid system compromises of Solar PV thus storage device is also modeled so that the energy from solar panels can be stored in battery and it can be used whenever the solar radiation is weak or when the generation is not feasible from solar cells, such as during cloudy days, rainy days. The storage device can also be used as the source of energy during the period of night. The battery is usually employed as a storage device for the hybrid system. This battery is only used by a solar cell to store excess energy so that it can be accessed during unavailability of Sun.

The description of storage device i.e. battery is given below:

Name of Battery: Surrette 4KS25P

Abbreviation: S4SK25P

Nominal Capacity: 1900Ah

Nominal Voltage: 4V

Round trip Efficiency: 80%

Minimum State of Charge: 40%

Minimum Battery Life: 5yrs

Lifetime throughput: 10569kWh

Suggested value: 10494kWh

Maximum charge rate: 1A/Ah

Maximum charge current: 67.5A [10]

6.5 Input unit cost of equipments:

Its need to be noted that the price listed in Table 3 is taken as the unit price of the equipments used in our system for simulation. It's done by collecting data from local market for the individuals.

Table.3 Unit price of components for simulation input [10-13]

Equipment	Size (kW)	Capital (Tk)	Replacement (Tk)	O&M
Wind scheme	2	150000	140000	500 Tk/yr
Diesel Generator scheme	10	80000	70000	.50 Tk/hr
Solar PV scheme	1	90000	80000	200 Tk/yr
Storage device	1	40000	35000	2000 Tk/yr
Converter	3	20000	18000	50 Tk/yr

* 1 dollar = 80 Tk

7. COMPLETE MODEL OF HYBRID SYSTEM:

The complete model of hybrid system consisting of Wind, Solar PV and Diesel generator as the individual generating schemes contributing for hybrid operation, storage device and converter for storing and conversion of power produced from solar panel is shown in Fig. 5.

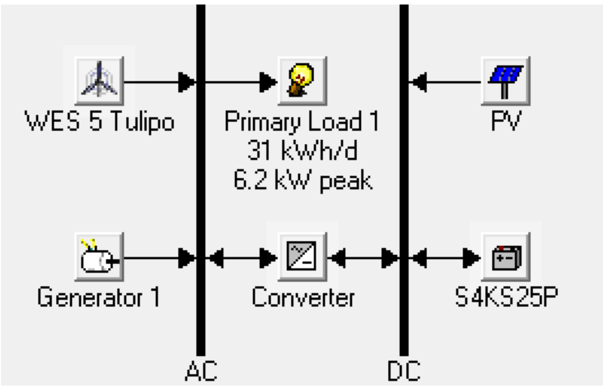

Fig. 5: Complete Model of Hybrid System

Here, by the HOMER software the simulated peak demand of primary load is 6.2kW and total energy consumption is 31kWh/day where calculated peak demand is 6 kW and total energy consumption is 37.1kWh/day. Simulated result is low from the calculated result as we given balanced input load to the HOMER software of different hours of a day.

The hybrid system consists of three individual generating units where the output from Wind turbine and Diesel Generator units are alternating in nature hence they are tied to AC bus-bar. Solar PV is tied to DC bus-bar because the output from solar panel is DC. The battery is also tied to DC bus-bar so that it can store the power delivered by solar panel when there is excess solar radiation during peak sun hours and deliver the required amount of power when the solar panel is not in operation that is during period of night, cloudy and rainy days etc. The converter is tied between AC and DC bus-bar. Converter converts the DC outputs of the PV system and battery into AC. The loads are considered to be AC loads.

8. SIMULATION RESULTS OF THE HYBRID SYSTEM:

The hybrid system was designed in HOMER by placing the appropriate input resource parameters for each individual scheme. After simulation different type of scheme has generated with their different energy system. Among them the hybrid system with 10kW Solar PV, 2pcs WES 5(each 2.5kW) wind turbine, 3kW diesel generator, 11 pieces Surrette 4KS25P battery and 7kW converter scheme is most cost effective from other different hybrid schemes as the levelized cost (COE) is only 19.2Tk, which is comparatively low from other schemes.

8.1 Electrical Results of the Hybrid System:

The production of electricity by individual scheme in hybrid system is given below in Table

Table.4 Electrical output of the system

Production	kWhr/yr	%
PV array	15,069	79
Wind turbine	2,033	11
Generator	1,836	10
Total	18,966	100

It is seen from above Table that PV array accounts for total of 79% of hybrid system production whereas Diesel Generator accounts for only 10% and Wind turbine accounts for 11% of total electrical energy produced by the hybrid system. Since the electricity produced by Solar PV scheme is more than any other scheme participating in the hybrid system thus is considered as the base load of the hybrid system

The monthly average electric production of hybrid system compromising of Solar PV, Diesel Generator and Wind is represented in a graph given below in Fig.6 which is obtained as a result after the simulation.

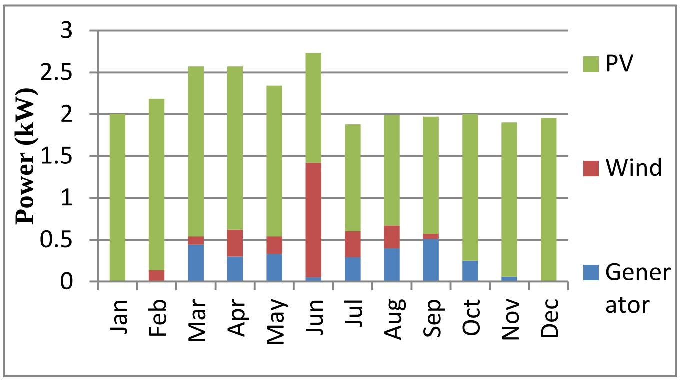

Fig.6: Monthly electric production of the Hybrid System

The consumption of electrical energy by AC primary load is 14603.82 kWh/yr which is 77% of the total electrical energy produced by the hybrid system. The excess electricity available from the system is about 4,632 kWh/yr.

8.2 Simulation Results for Solar Photovoltaic System:

The solar PV system participating in the hybrid system delivers 8KW of power to the load when operating in a hybrid system. The simulation results obtained for Solar PV is given below in Table 5.

Table.5 PV scheme results

Quantity	Value	Units
Rated capacity	10 .0	kW
Mean output	1.72	kW
Mean output	41.3	kW/d
Capacity factor	17.2	%
Total production	15,069	kWhr/yr
Minimum output	0.00	kW
Maximum output	9.92	kW
PV penetration	132	%
Hours of operation	4373	hr/yr
Level zed cost	4.68	Tk/kWh

From above Table it is seen that maximum output from solar PV is 9.92 kW when solar insolation is fully available and minimum output is 0 kW when the panel didn't get enough solar insolation to produce electricity. The total production of electricity from Solar PV system is 15,069 kWh and total hour of operation is 4,373hrs per year. The levelized cost only of this scheme is 4.68Tk.

8.3 Simulations Result for Wind Turbine System:

The Wind turbine system participating in the hybrid system has nominal capacity of 5kW with mean output of 0.23kW. The different simulation results obtained for Wind Turbine system while operating in hybrid manner with other system is given below in Table.6

Table.6 PV scheme results

Quantity	**Value**	**Units**
Rated capacity	5 .00	kW
Mean output	0.23	kW
Capacity factor	4.64	%
Total production	2033	kWhr/yr
Minimum output	0.00	kW
Maximum output	5.18	kW
Wind penetration	17.9	%
Hours of operation	4955	hr/yr
Level zed cost	10.5	Tk/kWh

It is seen from the above figure that maximum output from wind turbine is 5kW when wind speed is maximum and minimum output is 0.23 kW when the wind turbine didn't get enough wind speed to create rotational force to the rotor .The total production of electricity from wind turbine system is 2,033 kWh and total hour of operation is 4,995hrs per year. The Levelized cost only of this scheme is 10.5TK.

8.4 Simulation Result for Diesel Generator System:

The Diesel generator system participating in hybrid system has nominal capacity of 3kW with mean electrical output of 2.19kW with electricity production is 1,863kWh and total hour of operation is 851hrs per year. The marginal generation cost only of this scheme is 15.3TK. The different simulation results obtained for Diesel Generator system while operating in hybrid manner with other system is given below in Table7

Table.7 Simulation result for diesel generator

Quantity	Value	Units
Hours of operation	851	hr/yr
Number of starts	50	starts/yr
Operational Life	17.6	yr
Capacity factor	7.09	%
Fixed generation cost	16.2	Tk/hr
Marginal generation cost	15.3	Tk/kWh
Electricity production	1,863	kWh/yr
Mean electricity output	2.19	kW
Min electricity output	.90	kW
Max electricity output	3.00	kW

8.5 Simulation Results for Storage Device:

Battery was used as storage device for the hybrid system. The capacity of each battery was 1900Ah. The simulation result for battery is given in Table 8.

Table 8: Storage Device results

Quantity	**Value**	**Units**
Nominal capacity	91.2	kWh
Usable nominal capacity	54.7	kWh
autonomy	42.1	hr
Lifetime throughput	126823	Tk/ kWh
Battery wear cost	3703	Tk/ kWh
Energy In	8,493	kWh/yr
Energy Out	6,814	kWh/yr
Storage depletion	22	kWh/yr
Losses	1657	kWh/yr
Annual throughput	7618	kWh/yr

9. COST SUMMARIES:

The cost summary of hybrid system in terms of Net Present cost by component size and cost type obtained after simulation is given below in Fig. 7 and Fig. 4 respectively.

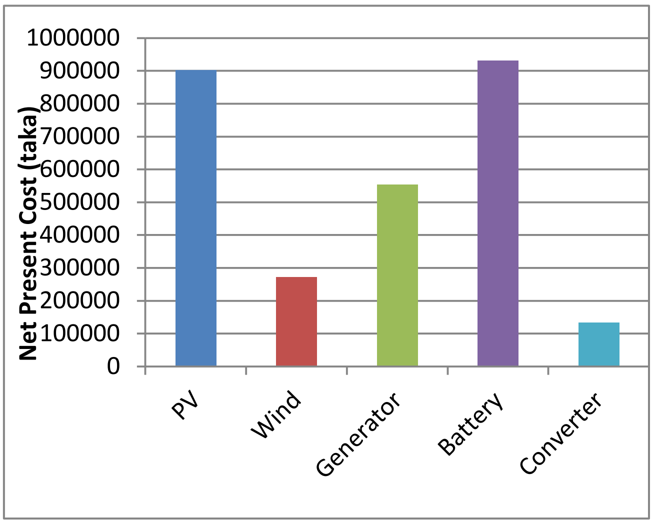

Fig 7: Cost summary by component type (Taking 1 dollar = 80 Taka)

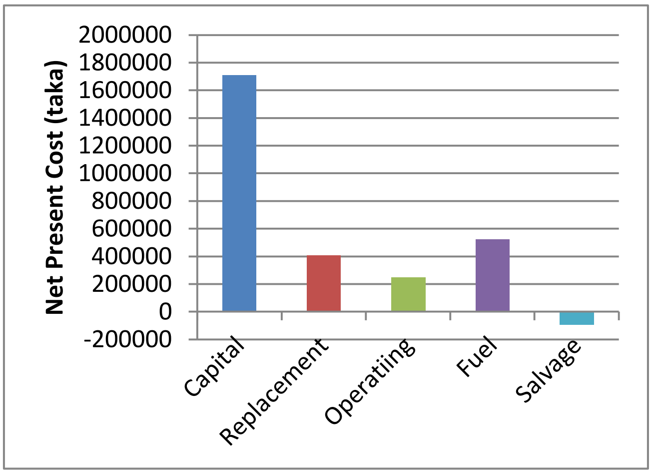

Fig. 8: Cash Flow Summary by Cost type (Taking 1 dollar = 80 Taka)

The economics of hybrid system is represented above where the overall costs associated with the system is given in individual manner of each participating scheme as well as the overall system considered as a whole. The costs associated with hybrid system is given in both component type and cost type.

10. SUMMARIZED RESULT

Renewable energy systems are very much site specific and designing such a system is complicated. Solar and wind system are most suitable for electrification of isolated remote areas in developing countries like Bangladesh.[14] Our study deals with the design of hybrid power system for one of the rural remote place named Sandip-para of Bangladesh and also observe the economics associated with designed hybrid system. In this study, each of the individual scheme participating in hybrid system i.e. Wind, solar PV and Diesel generator was modeled separately by defining real input parameters for each of the scheme. The economics associated with hybrid system was analyzed so that the cost of energy (COE) produced from hybrid system would be affordable for the people living in that region. From HOMER simulation we obtain minimum per kWh cost (COE) of Hybrid system is 19.198Tk Tk.

Here, Total Net Present Cost (NPC): 27, 93,315Tk

Levelized Cost of Energy (COE): 19.198Tk/kWh

Operating Cost: 84,692Tk/yr.

If the capital amount of money will be loaned from a bank with interest rate then cost will be,

Initial Capital cost of the system = 17, 10,667Tk

At 6% interest rate, system fixed capital cost = 1,02640Tk

Total initial capital cost of the system = 18, 13,307Tk

11. PAYBACKS PERIOD ANALYSIS

Payback period means that the number of years required recovering the cost of the investment and cost benefit analysis of our system. [15] Here we have to consider different rate of per kW hour as the fuel price as well as the electricity price is increased day by day.

a) Considering 1kWh = 12Tk

Total capital cost of the hybrid system = 17, 10,667Tk

Annual income = 175245.84Tk [As annual consumption of electricity = 14603.82kWh]

So, payback period in year = $\frac{1710667}{175245.84} = 9.76 \approx 8$ years

b) Considering 1kWh = 15Tk

Total cost of the hybrid system = 17, 10,667Tk

Annual income = 219057.3Tk

So, payback period in year = $\frac{1710667}{219057.3} = 7.8 \approx 8$ years

c) Considering 1kWh = 18Tk

Total cost of the hybrid system = 17, 10,667Tk

Annual income = 262868.76Tk

So, payback period in year = $\frac{1710667}{262868.76} = 6.5 \approx 7$ years

12. CONCLUSION

Using of hybrid power generations came forward due to high prices of generating power from oil and also due to the limited availability of such kind of non-renewable sources. Hybrid system can optimize the power supply especially in off-grid rural areas. However it is still considered expensive and difficult to combine various energy sources together .The expense is only for one time with a life span of about 20-25 years. So it can easily be considered. The simulated hybrid system for sandip-para can be used in any off grid area of Bangladesh for electrification as solar radiation is used as primary source of energy which is abundant throughout the country; with levelized cost (COE) of 19.2Tk (.24$).

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