ISSN 2229-5518

Design and Cost Analysis of a Centralized Solar Photovoltaic System for Rural Area

Md. Tanvir Ahammed, Md. Azizul Islam, Md. Tariquzzaman, Md. Mehedi Hasan

Abstract— This paper presents a centralized solar photovoltaic (CSPV) system to show the economic feasibility of an off-grid isolated renewable energy system for rural areas; taking Chor Kapna as model which is in Nageswari upzila of Kurigram district of Rangpur division, Bangladesh. The centralized solar photovoltaic system uses a photovoltaic (PV) array to supply power for lights and small appliances and needs rechargeable storage batteries, so that power is still available at night and on cloudy days. A step-up DC-DC converter is used to transmit power at 120V in order to reduce transmission line losses. The system would be located at the center of the village and connected to a network of 120V DC transmission lines. HOMER (Hybrid Optimization Model for Electric Renewable) software is used to analyze the available data and economic viability of the proposed CSPV power system. Results have been found that the most efficient economic way for electrifying the rural area is CSPV system compared to traditional solar home system (SHS).

Index Terms— Photovoaltaic System, Reduction of tranmission line loss, Centralized solar photvoaltaic system, Step-up DC-DC converter, 120V DC, HOMER, Cost Analysis.

1 Introduction

ENERGY is one of the most important basic ingredients required to alleviate poverty and to bring about socio-economic development of a country. Fossil fuel, sunlight, air, water source and nuclear power plant are the sources of energy throughout the world. Major energy source is still fossil fuel but the reserve is declining. Fossil fuel is being used though it emits greenhouse gases for global warming which is a threat to climate change and sustainable development. In this situation Solar energy, on the other hand, is renewable, environmentally approachable, and unlimited clean source of energy. It is expected that the effective utilization of solar energy can fulfil present and future demand of electric energy.

In most developing countries like Bangladesh most of the population living in the remote and rural areas do not have access to the electrical grid. Yet there are alternatives. Renewable energy can offer an ideal source of electricity for a rural or other isolated place far from national grid. At present, the rural areas, which are not connected to the grid, solar home system (SHS) can be used to meet a household's energy demand fulling basic electric needs. But the installation and maintenance cost are more [1]. The centralized photovoltaic system can optimize the electricity demand in the rural with low installation and maintenance cost. Centralized solar photovoltaic system refers to large-scale solar plant installations, in usually remote locations [2]. They are large solar power generation farms, producing substantial electricity, that is fed into the certain remote area and grid.

In order to make effective utilization of solar energy using photovoltaic module extensive researches have been finished. A pilot centralized solar power station for remote village is very much promising to harvest electrical energy from solar arrays and reported in [3].

- **Md. Tanvir Ahammed**, *Lecturer, Jessore University of Science and Technlogy, Jashore, Bangladesh, E-mail: tanvir.eee10@gmail.com*
- **Md. Azizul Islam**, *B. Sc in EEE, Jessore University of Science and Technology, Jashore, Bangladesh, E-mail: azizulislam140@gmail.com*
- **Md. Tariquzzaman**, *Lecturer, Jessore University of Science and Technology, Jashore, Bangladesh, E-mail: mabcdswapnil@gmail.com*
- **Md. Mehedi Hasan**, *Lecturer, Jessore University of Science and Technology, Jashore, Bangladesh, E-mail: mhdhsn48@gmail.com*

The comparison between Centralized versus distributed (power optimizer) PV system was presented in [4]. Centralized Solar PV systems for static loads using constant voltage control method was shown in [5]. A hybrid system for standalone solar application is presented in [6] which combines wind turbine and PV module. In previous studies [7-10] the net present cost, cost of energy, operating cost are comparatively large. Therefore, the main aim of this paper is to study the economic feasibility of centralized photovoltaic system to meet the load requirement on a specific area. The cost benefit analysis of the system was done using HOMER software. For a comparison purpose, we estimated the total cost of the solar home system of the certain rural area with the total cost of our proposed system.

In this paper 4 kW centralized photovoltaic system is proposed and designed using HOMER software. The cost optimization analysis is also done by using HOMER software.

2 Description of The Proposed system

Now a day's solar systems have become popular throughout the world. Here a CSPV system which will provide 4 kW power for household appliances is proposed. The centralized PV System will generate power at 24 V DC from solar panel and distribute at 120 V DC to the household appliances such as lights and Solar fans. Here 120 V is selected as DC loads are available at this voltage and transmission line losses are reduced significantly. The maximum demand hours of the households in our study area is taken six hours in a day.

2.1 System Configuration

Our proposed CSPV system which consists of PV array, a 24 V DC-120 V DC converter, MPPT charge controller, battery bank and loads. figure 1, shows the block diagram of the proposed CSPV system. Lead acid batteries can be used due to their low cost and maintenance. The charge controller controls charging and discharging of the battery bank.

ISSN 2229-5518

2.2 Description of Study Area

The name of the study area is Chor Kapna which lies in Nageswari Upazila of Kurigram district. (Latitude: 25.8831 N, Longitude: 89:7419 E). Figure 2 shows the study area. It's one of the non-grid-connected area of Bangladesh and about 75 families live here. Most of the peoples living here are be governed by upon agriculture for their livelihood. The people of this region familiarity the continuous daylight throughout the year although the solar radiation of winter season remains comparatively lower than that of summer season. The average solar radiation intensities of about 4.58kWh/day with average sunshine hour of 8 hours/day of about 300 days of sun a year is available in this region.

2.3 Load Estimation of Study Area

Electricity demand for 10 high class households:
Five CFL bulbs = 10 W (power rating of each bulb) ×5 (no. of bulb)
Two solar Fans = 15W (power rating of fan) ×2 (no. of fan)
Total load high class house hold =800 W
Electricity demand for 40 middle class households:
Four CFL bulb = 10 W (power rating of each bulb) ×4 (no. of bulb)
One solar Fan = 15W (power rating of fan) ×1 (no. of fan)
Total load mid class households=2200 W
Electricity demand for 25 low class households:
Four CFL bulb = 10 W (power rating of each bulb) ×4 (no. of bulb).
Total load low class households =1000 W
Total load demand= 800W + 2200W + 1000W = 4kW
Total energy demand = 4 kW * 6h (hours of operation) = 24 kWh/day
Figure 3, shows the daily load profile of our study area and Fig. 4, shows the monthly load variation of this area.

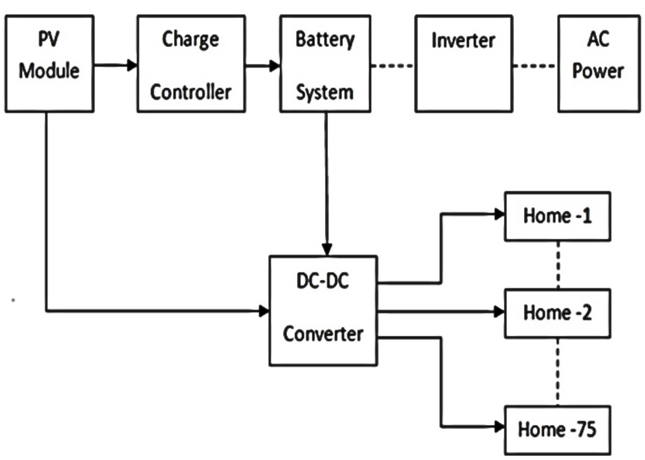


Fig. 1. Block diagram of the proposed CPVS.

Fig. 2. Chor Kapna a top view from Google Earth [11].

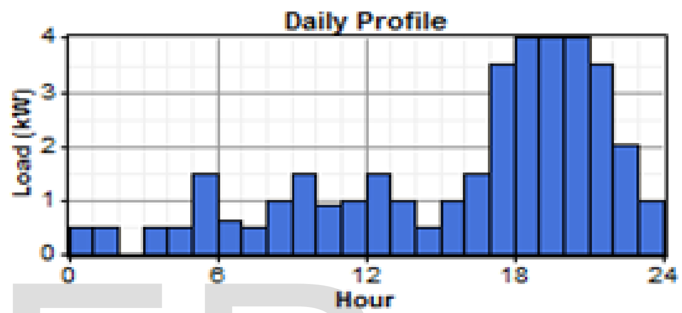


Fig. 3. Daily load curve of the rural area.

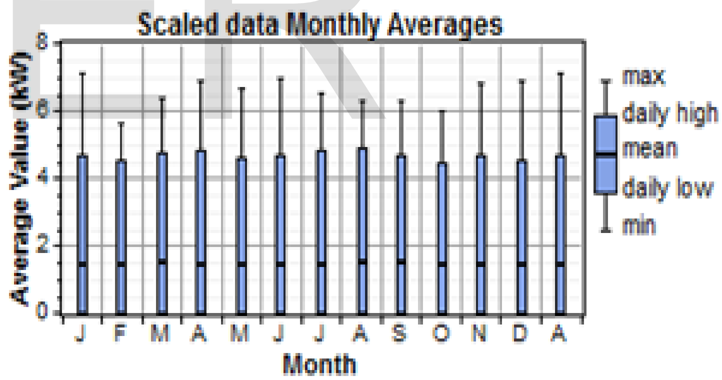


Fig. 4. Monthly load variation of the rural area.

2.4 Solar Resource

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. The solar radiation data for various months throughout the year in chor kapna is shown in Table 1. By analyzing the solar radiation for each month, it was found that the maximum solar radiation was found for the month of April with daily radiation of 5.840 kWh/m²/day whereas the minimum radiation was found for the month of August with daily radiation 3.87 kW/m²/day. The average radiation throughout the year was 4.56 kWh/m²/day.

TABLE 1
SOLAR RADIATION THROUGHOUT THE YEAR [12]

Month	Clearness Index	Daily Radiation ($kWh/m^2/d$)
January	0.623	4.093
February	0.584	4.502
March	0.580	5.302
April	0.563	5.840
May	0.494	5.467
June	0.412	4.648
July	0.348	3.879
August	0.392	4.148
September	0.406	3.871
October	0.591	4.789
November	0.627	4.269
December	0.630	3.899

3 HOMER Simulation Model of Proposed System

HOMER is an electrical system design and simulation package which simplifies the task of evaluating design options for both off-grid and grid-connected power systems for remote, stand-alone, and distributed generation (DG) applications. Homer's optimization and sensitivity analysis algorithms allow the user to evaluate the economic and technical feasibility of a large number of technology options and to account for uncertainty in technology costs, energy resource availability and other variables. It was initially produced by NREL, but is now a commercial organization HOMER ENERGY. Figure 5, shows the simulation model of CSPV. Here, by the HOMER software the simulated peak demand of primary load is 7.2 kW and total energy consumption is 36 kWh/day.

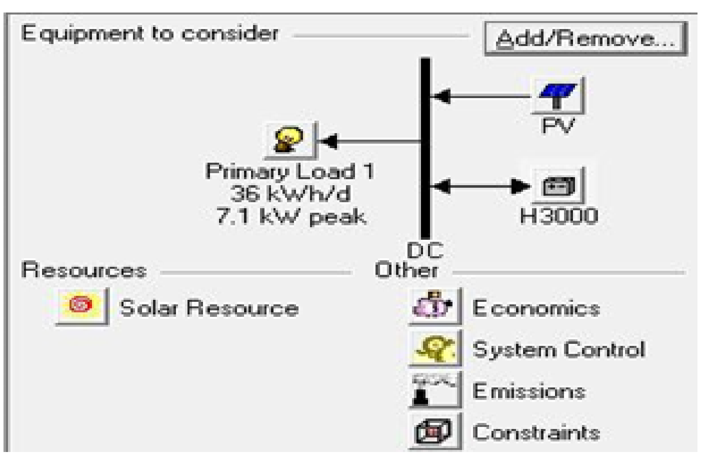


Fig. 5. Simulation model of proposed CPVS.

TABLE 2
UNIT PRICE OF COMPONENTS FOR SIMULATION INPUT [13-14]

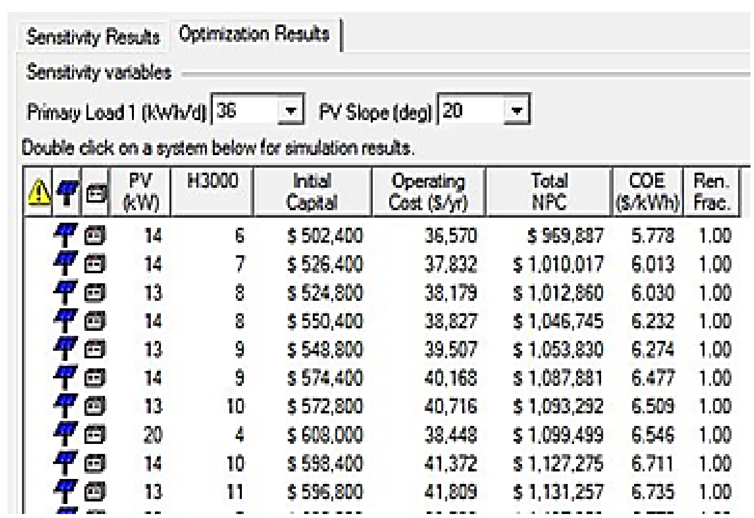
Equip-ment	Size (kW)	Capital (Tk)	Replace-ment (Tk)	O&M
Solar PV scheme	4	1,02400	90000	2000 Tk/year
Battery	1	24,000	20000	2000Tk/year
Converter	4	25,000	20000	500 Tk/year

4 Simulation Result

In order to design CSPV system, HOMER simulates thousands of possible integrated components discards infeasible configurations and puts all feasible systems in order based on total net present cost. The next step after simulation is the result analysis which includes optimizations results, economic analysis, emission analysis and grid extension comparison result. The proposed CSPV system here is designed in standalone, the net present cost (NPC), cost of energy (COE), operating cost for the designed power supply is calculated. Table 2, shows the per unit price of different components used in simulation input.

4.1 Optimization of Result

HOMER performs the optimization process in order to determine the best solution in terms of component size and total net present cost of hybrid renewable energy system based on several combinations of equipment. In Fig. 6, the results represent different combination of components of PV array system, battery and converter as optimum combination. The total net present cost for optimum combination is 969887 Tk and cost of energy (COE) is 5.778 Tk/KWh with total renewable fraction of 1%. From the optimization result, we choose the row of the



PV (kW)	H3000	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.
14	6	$ 502,400	36,570	$ 969,887	5.778	1.00
14	7	$ 526,400	37,832	$ 1,010,017	6.013	1.00
13	8	$ 524,800	38,179	$ 1,012,860	6.030	1.00
14	8	$ 550,400	38,827	$ 1,046,745	6.232	1.00
13	9	$ 548,800	39,507	$ 1,053,830	6.274	1.00
14	9	$ 574,400	40,168	$ 1,087,881	6.477	1.00
13	10	$ 572,800	40,716	$ 1,093,292	6.509	1.00
20	4	$ 608,000	38,448	$ 1,099,499	6.546	1.00
14	10	$ 598,400	41,372	$ 1,127,275	6.711	1.00
13	11	$ 596,800	41,809	$ 1,131,257	6.735	1.00

Fig. 6. Optimization result of the system. *All the currency values are considered in terms of Tk. (Taka, Bangladeshi Cur-

rency) instead of Doller sign (USD).

figure 6 according to lowest net present cost (NPC) and cost of energy (COE).
Total energy produced annually by PV array = 20443 kWh/yr
Total energy consumption by load = 13,132 kWh/yr
Excess electricity =5874 kWh/yr
Unmet electric load=8.19 kWh/yr

Figure 7, shows the monthly average electricity production. Table 3, shows the net present cost of the proposed CSPV system. The cash flow diagram of CSPV system is shown in figure 8. Table 4, shows the annualized cost of the proposed system.

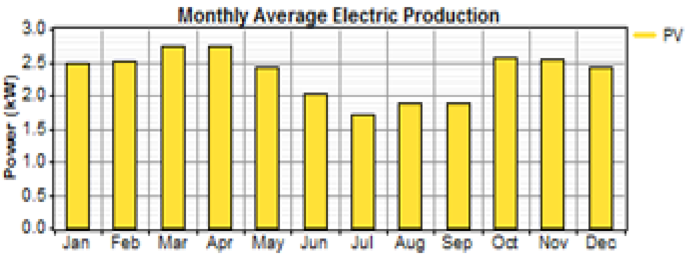


Fig. 7. Monthly average electricity production.

TABLE 3
SNET PRESENT COST OF THE PROPOSED SYSTEM

Component	Capital (Tk)	Replacement (Tk)	O&M (Tk)	Salvage (Tk)	Total (Tk)
PV	358,400	98,219	89,484	-55,046	491,056
Battery (H3000)	144,000	181,484	153,400	-53	478,831
Total System	502,400	279,703	242,884	-55,099	969,887

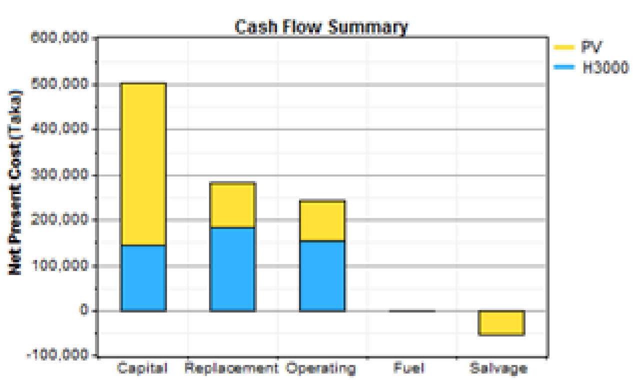


Fig. 8. Summery of net present cost of the system by cost type.

TABLE 4
ANNUALIZED COST OF THE SYSTEM

Component	Capital (Tk/y)	Replacement (Tk /y)	O&M (Tk /y)	Salvage (Tk /y)	Total (Tk/y)
PV	28,036	7,683	7,000	-4,306	38,414
Battery bank	11,265	14,197	12,000	-4	37,457
System	39,301	21,880	19,000	-4,310	75,871

Fig. 9. Cost comparison graph of CSPV system and SHS [15].

5 Cost Summary

The cost summary of the CSPV system in terms of Net Present Cost by cost type obtained after simulation is given below in Figure 8. From Table IV, we can say that-

Total net present cost of the CSPV system = 969887 Tk

The capital cost of system is about 502,400 Tk and must be expenditure at the start of its launching. The operating cost is invariable during the 25 years, but the replacement varies in 25 years due to different lifetime for battery and converter. The salvage cost can signify that selling some parts of the system which could work after the system lifetime and it is shown such as a returned diagram which is subtracted from capital cost of the system. HOMER software computes this time duration and subtracts it from the capital cost by the title of salvage cost.

Here a simulation also performed to analyze Net Present Cost of individual solar home system and the total cost of the solar home system (SHS) of the rural area (chor kapna) is 16,25,000 Taka (Tk). Figure 9, shows the cost comparison between centralized photovoltaic system (CPVS) and solar home system of the rural area (Chor Kapna).

4 Conclusion

In this work, a centralized solar photo voltaic system has been proposed to supply electricity for rural area which named Chor Kapna of kurigram district of Bangladesh. The proposed CSPV is located at the center of the village and connected to a network of 120 V DC transmission lines. The centralized photo voltaic system composed of 14 kW PV array, storages battery and converter that can supply 36 kWh/day energy consumption with a peak demand of 7.1 kW in the study area. The cost optimization analysis by using HOMER shows that the net present cost of the system is 9,69,887 Tk, cost of energy is 5.778 Tk/KWh, operating cost is 36,570/year during projection period of 25 years. In order to compare CSPV system with solar home system the total cost of SHS have been estimated and it is found 16,25000 Tk. of the SHS for 75 households. The total cost of the proposed CPVS is 40% less than that of SHS for 75 households. So, the centralized PV system provides a cost-effective alternative to the SHS.

Acknowledgment

The authors wish to thank Md. Azizul Islam and Omborish Chandra Barban for their continuous support and hard work.

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