Feasibility Study of Hybrid Energy Systems for Remote Area Electrification in Odisha, India by Using HOMER

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Abstract- Hybrid energy systems are successfully applied in areas where grid extension is practically impossible or uneconomical. This paper reports the results of optimization of hybrid energy system model for electrification of remote village Gobindapur, located at the foot hills of Similipal forest (Latitude $21^0$55' N and Longitude $86^0$34' E) of Mayurbhanj district of Odisha in India. The model is developed with the objective of minimizing cost function based on demand and potential constraints. The model has been optimized using HOMER (Hybrid Optimization Model for Electric Renewable) software (2.68 version) package developed by National Renewable Energy Laboratory (NREL), Colorado, USA. From the load demand, the capital cost, cost of energy for different types of resources and optimised configuration of hybrid system are determined.

Keywords- Hybrid, PV, insolation, HOMER

1. Introduction

In India, over 80,000 villages remain to be un-electrified and particularly in the state of Odisha, 9326 villages are still to be electrified. There is difficulty to supply electricity due to inherent problems of location and economy of these places. The costs to install and service the distribution lines are considerably high for remote areas. Also there will be a substantial increase in transmission line losses in addition to poor reliability. Like other developing countries, India is characterised by severe energy deficit. In most of the remote and non-electrified sites, extension of utility grid lines experiences a number of problems such as high capital investment, high lead time, low load factor, poor voltage regulation and frequent power supply interruptions. Solar panels can be used successfully for rural electrification, bringing power to the most remote parts of a region. A recent study by the MNES on comparison of relative cost of electrification of remote villages through conventional grid and solar photovoltaic power basing on net present value of life cost over a period of 20 years reveals that the solar electrification is more economical for villages located beyond 3 kms in hilly areas and 7 kms in plains from the grid [10]. Moreover potential PV Systems when used on a large scale cuts down the need for extending the distribution grids in rural areas.

A hybrid energy system consists of two or more energy systems, an energy storage system, power conditioning equipment and a controller. Examples of energy systems commonly used in hybrid configurations are small wind turbines, photovoltaic systems, micro hydro, biomass, diesel generator and fuel cells. The Hybrid Energy System (HES) has received much attention over the past decade. It is a viable alternative solution as compared to systems, which rely entirely on hydrocarbon fuel. Apart from this, it has longer life cycle. Moreover, for off-grid power supplies, a diesel generator (DG) system is most attractive because of its low capital inspite of higher operation and maintenance cost and higher CO_2 emission [17]. In some cases, diesel generator is not cost effective due to high fuel transportation cost to remote areas. But, the environmental issue is a major concern, particularly emission of carbon dioxide from the DG sets. This led engineers and planners to find a sustainable and environmental friendly solution of meeting power demand through renewable energy sources [1],[3]. For systems employing totally clean renewable energy, high capital cost is an important barrier. However, we can produce green power by adding different renewable energy sources to diesel generator and battery, which is called a hybrid system. Optimization of a hybrid energy system is site specific and it depends upon the resources available and the load demand.

Odisha receives an abundance of solar radiation throughout the year except for some interruption during the monsoon and winter seasons and has a vast potential for harnessing large amount of solar power of about 8000 MW (Table-1). Similarly wind energy potential is 910 MW and small hydro power project is of 120 MW [15]. Utilizing hybrid power system consisting of solar-wind or solar-wind-hydro (where there is potential of hydro power) is the best alternative sources for rural electrification in areas which is far away from grid [4],[16].

Table-1. Potential of Renewable Energy in Odisha

Sl. No	Renewable Energy Source	Gross Potential (MW)	Feasible Potential (MW)
1	Solar Photovoltaic	40,000	8000
2	Solar Thermal	10000	2000
3	Wind	1700	910
4	Biomass-paddy husk	300	250
5	Biomass – paddy straw	600	250
6	Other Biomass	800	250
7	Bio-diesel	300	150
8	Small Hydro Project	120	120
	Total	53820	11820

Many hybrid systems sizing have been studied and optimized by the researchers by using HOMER [6],[7],[8],[9].

Abha R. and Fernandez E.[10] made a study at IIT, Roorkee for size optimization of a hybrid energy system for a remote region in India by using HOMER. The optimised system with lower cost of energy (COE) was determined for the area.

Al-Badi *et al* [11] made a study to determine the optimum size of systems to fulfil the electrical energy requirements of remote sites located in Hajer Bani (HB) Hameed in the North of Oman, Masirah Island and the Mothorah area in the South of Oman by using HOMER. A list of feasible power supply systems according to their net present cost were suggested.

Afzal *et al* [12] studied the feasibility of using different hybrid systems for the same load demand in two remote locations in southern India. An optimisation model of a hybrid renewable system was prepared. After simulating all possible system equipment with their sizes, a list of many possible configurations were suggested on the basis of net present cost.

Bindu and Parekh [13] made a study on modelling and simulation of distributed energy system with PV-Wind-Diesel hybrid system by using HOMER. They concluded that at lower wind speeds, PV/Battery/Diesel configuration is optimum while at medium and higher wind speeds, Wind/PV/Battery and PV/Wind/Diesel/Battery configuration are feasible respectively.

Location of the site

The present study is for developing a feasible model for electrifying a remote tribal village called Gobindapur (Pithabata) under Kuchilaghati Panchayat of Samakhunta block which is located at the foothills of Similipal reserve forest, close to Sitakund waterfall. This village is not yet been electrified nor to be electrified in near future. In this village there are 63 tribal families residing and the houses are scattered. They are presently using kerosene lamps in evening and early morning. This model will definitely help to supply electricity to this village for lights, radio, television and for using other small appliances. Electric lights can enable these families to extend their days after sunset productively and enjoyable by studying, working, or simply cooking and eating dinner in a well lit home This model was analysed by using HOMER.

The proposed model suggested for this village is shown in Fig.1.

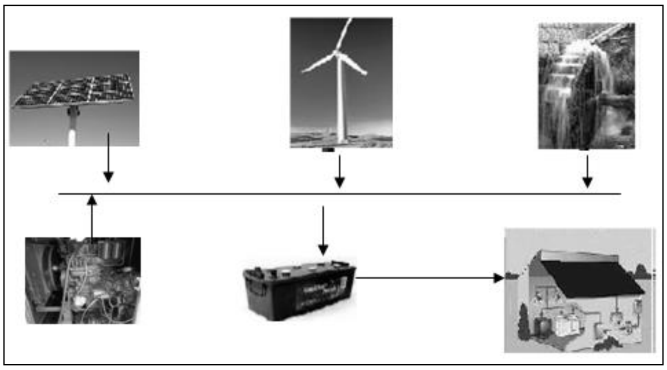
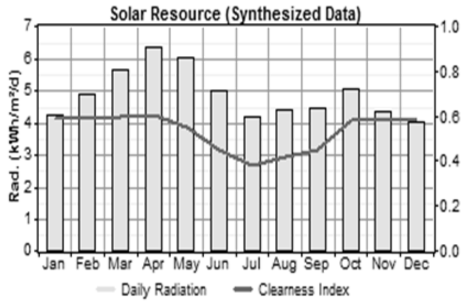


Fig. 1. Hybrid system for model optimisation

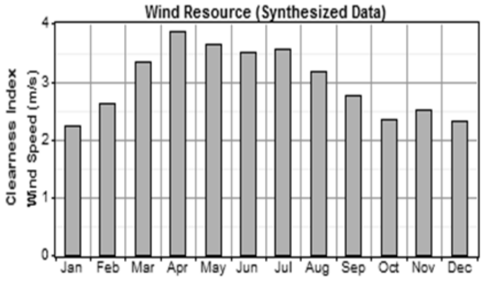
Renewable energy resources at the site

The most important factor in developing a hybrid energy system is its geographical location and availability of renewable resources. This study area located at Gobindapur village have all the wind, solar and hydro energy for generating sufficient power for electrifying this area.

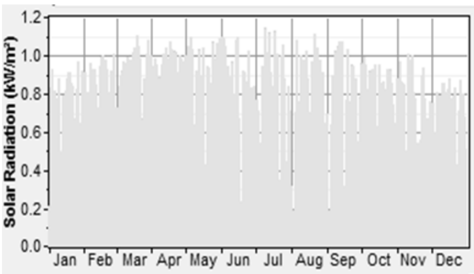
For this hybrid system, the meteorological monthly data of solar insolation and wind speed for the area (Longitude 86°34' East and Latitude 21°55' North) are imported from the NASA metrological website [5] for the analysis by HOMER which synthesised daily radiation and hourly wind speed values. Our average wind speed is 2.99 m/s and average daily radiation is 4.88 KWh/m^2 (Fig. 2 &Table 2).



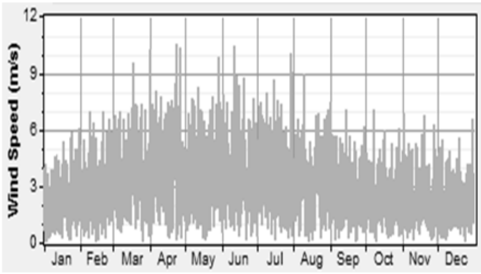
Solar radiation variation in different months



Wind speed variation in different months



Hourly solar radiation



Hourly wind speed

Fig. 2. Solar radiation and wind speed variation in different months

Table 2. Weather data of the site

Month	Clearness Index	Average solar radiation	Wind speed
		(kWh/m^2/day)	(m/s)
Jan	0.588	4.249	2.24
Feb	0.591	4.879	2.62
Mar	0.596	5.667	3.35
Apr	0.606	6.363	3.87
May	0.550	6.034	3.63
Jun	0.449	4.968	3.50
Jul	0.379	4.164	3.57
Aug	0.415	4.409	3.18
Sep	0.452	4.436	2.76
Oct	0.584	5.023	2.35
Nov	0.583	4.338	2.52
Dec	0.583	4.007	2.31

Load analysis

The proposed hybrid power system is designed to ensure the electric supply to all the 63 households including one agricultural farm with an average energy consumption of 148 kWh/d with a peak load of 23 kW. Fig. 3 shows the daily load profile of the site.

The main aim of this study is to identify the most economic and appropriate power supply system for this village. There is one agricultural farm inside the forest having one rest shed. The load demand of the village is given in Table 3.

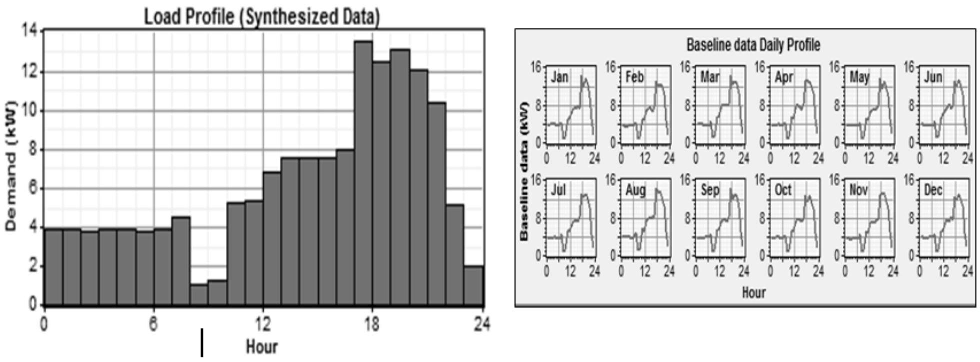


Fig. 3. Hourly load profile of the village in a day

Table 3. Electric load demand of the village

	Particulars	Load details	kWh/day
A	Agricultural farm		
	2 hp Pumpset running 4 hrs a day	80% load of (746 x 2) = 1194 W/h	4.77
	0.5 hp pump for drip system running for 10 hours/day	80% load of 373W = 298 W/h	2.98
	2 nos of CFL (15W) for 5 h/day	30x5	0.15
B	Village houses (63 nos)		
	3 nos of CFL (15W) for 5 h/day/house	225 x 63	14.18
	Ceiling fan(60W)- 2 nos for 10 h/day/house	1200 x 63	75.60
	TV (90 W)-1 no. for 5 h/day	450 x 63	28.35
	Electric iron (750W) for0.33 h/day/house	247.5 x 63	15.59
	Mixer (450W) for 0.17 h/day/house	76.5 x 63	4.82
C	Misc. load/ house/ day	24 W x 63	1.51
	Total		148.00

Keeping in view that in future, if some families (say 50 families) will have one refrigerator (125W) running on load for 8 hours, then 125 W x 8 x 50 = 50.0 kW extra to be consumed. Hence, considering future increase in load due to use of appliances, load of 200, 250 and 300 kWh/d were considered along with present demand of 148 kWh/d for analysis. Average stream flow rate 188 L/s was considered for hydro turbine.

System analysis

In all the simulations, 5% annual maintenance cost (except solar PV), salvage value of 10 % (except battery) and annual nominal interest (Actual interest – inflation rate) of 6% were taken.

The system configuration with their unit cost is given below.

Equipment	Solar PV	Wind turbine	Hydro turbine	DG	Battery,24 nos	Inverter	Rectifier
Rated capacity	2 kWp	5.1 kWp	44.1 kWp	16 kW	200 A 12 V	5 KW	5 KW
Cost, $/kW	5000	1700	1587	450	$250/battery	1000	1000

A. Solar-wind-hydro-DG system (Model- I)

The schematic of this model and the cash flow summary of the system are shown in Fig.4 and 5 respectively while the brief summary of the model at different loads with 4.88 kWh/m^2/d of solar radiation, 2.99 m/s wind speed and diesel price of $0.9 /litre is shown in Table 4.

It was found that the operating cost increases from $12,416/yr to $16,544/yr as the load increases from 148 to 250 kWh/day and this may be due to higher amount of diesel consumption at higher loads. The COE decreased from $0.375 to $0.294/kWh as the load increased from 148 to 250 kWh/day. But this system with proposed configuration will not support the load of 300 kWh/d.

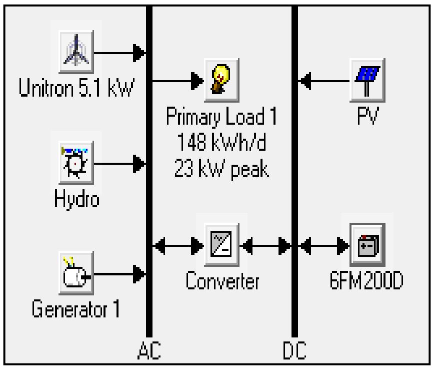
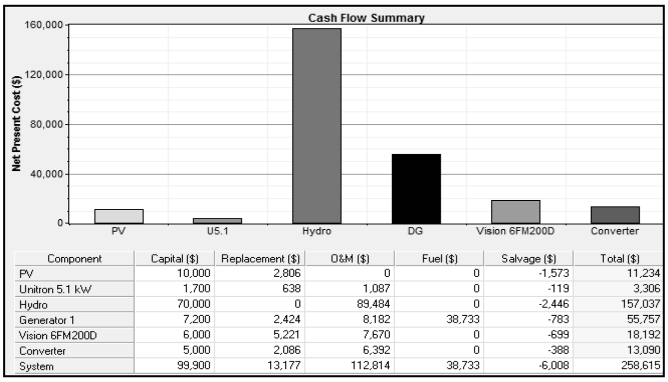


Fig. 4. Schematic of the solar-wind-hydro-DG system



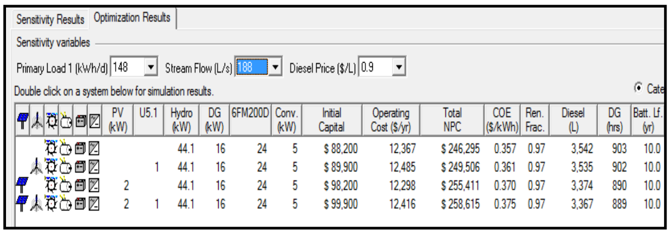
Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
PV	10,000	2,806	0	0	-1,573	11,234
Unitron 5.1 kW	1,700	638	1,087	0	-119	3,306
Hydro	70,000	0	89,484	0	-2,446	157,037
Generator 1	7,200	2,424	8,182	38,733	-783	55,757
Vision 6FM200D	6,000	5,221	7,670	0	-699	18,192
Converter	5,000	2,086	6,392	0	-388	13,090
System	99,900	13,177	112,814	38,733	-6,008	258,615

Fig. 5. Cash flow summary of solar-wind-hydro-DG system

Table 4. Brief summary of solar-wind-hydro-DG system with $ 0.9/L diesel cost and 188 L/s flow rate

	148 kWh/d	200 kWh/d	250 kWh/d
Total net present cost	$ 258,615	$283,824	$342,390
Levelized cost of energy	$0.375/kWh	$0.304/kWh	$0.294/kWh
Operating cost	$ 12,416/yr	$13,997/yr	$16,544/yr
Diesel consumption	3367 litres/yr	4284 litres/yr	5061 litres/yr

The NPC, operating cost and annual diesel consumption of solar wind-hydro-DG system along with other systems at existing resources condition of 4.88 kWh/m^2/d solar insolation, 2.99 m/s wind speed, diesel price of $ 0.9/litre and stream flow rate of 188 litres/s at 148 kWh/d load demand is shown in Fig. 6.



Sensitivity Results | Optimization Results

Sensitivity variables

Primary Load 1 (kWh/d) 148 | Stream Flow (L/s) 188 | Diesel Price ($/L) 0.9

Double click on a system below for simulation results.

PV (kW)	U5.1	Hydro (kW)	DG (kW)	6FM200D	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)	Batt. Lf. (yr)
		44.1	16	24	5	$ 88,200	12,367	$ 246,295	0.357	0.97	3,542	903	10.0
	1	44.1	16	24	5	$ 89,900	12,485	$ 249,506	0.361	0.97	3,535	902	10.0
2		44.1	16	24	5	$ 98,200	12,298	$ 255,411	0.370	0.97	3,374	890	10.0
2	1	44.1	16	24	5	$ 99,900	12,416	$ 258,615	0.375	0.97	3,367	889	10.0

Fig. 6. Cost summary of the system at different configuration of equipments

B. Solar-Hydro-DG system (Model- II)

The schematic of this model is shown in Fig.7 while the brief summary of result is presented in Table 5. It was found that the operating cost increases from $12,298/yr to $16,430/yr as the load increases from 148 to 250 kWh/day and this may be due to higher amount of diesel consumption at higher loads. However, the COE decreased from $0.370 to $0.291/kWh as the load increased from 148 to 250 kWh/day. Also the diesel consumption increases from 3374 litres to 5070 litres as the load increases from 148 to 250 kWh/d. This system with proposed configuration will also not support the load of 300 kWh/d.

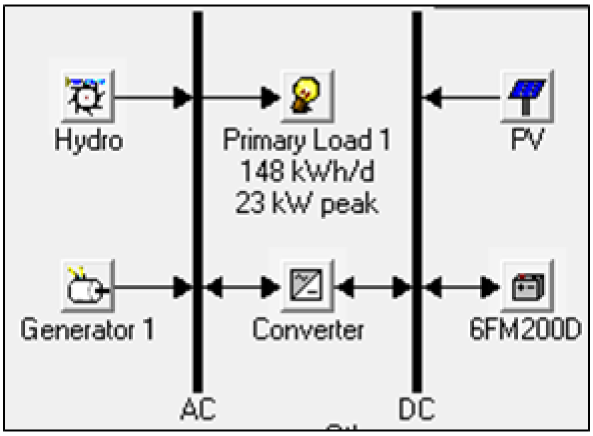


Fig. 7. Schematic of the solar-hydro-DG system

Table 5. Cost summary of solar-hydro-DG system with $ 0.9/L diesel cost and 188 L/s flow rate

	148 kWh/d	200 kWh/d	250 kWh/d
Total net present cost	$ 255,411	$280,623	$339,231
Levelized cost of energy	$ 0.370/kWh	$0.301/kWh	$0.291/kWh
Operating cost	$ 12,298/yr	$13,879/yr	$16,430/yr
Diesel consumption	3374 litres/yr	4293 litres/yr	5070 litres/yr

C. Wind-Hydro-DG system (Model- III)

The schematic of this model is shown in Fig.8 while the brief summary of result is presented in Table 6. It was found that the operating cost increases from $12,485/yr to $17,408/yr as the load increases from 148 to 250 kWh/day and this may be due to higher amount of diesel consumption at higher loads. However, the COE decreased from $0.361 to $0.286/kWh as the load increased from 148 to 250 kWh/day. Also the diesel consumption increases from 3535 litres to 5477 litres as the load increases from 148 to 250 kWh/d. This system with proposed configuration will also not support the load of 300 kWh/d.

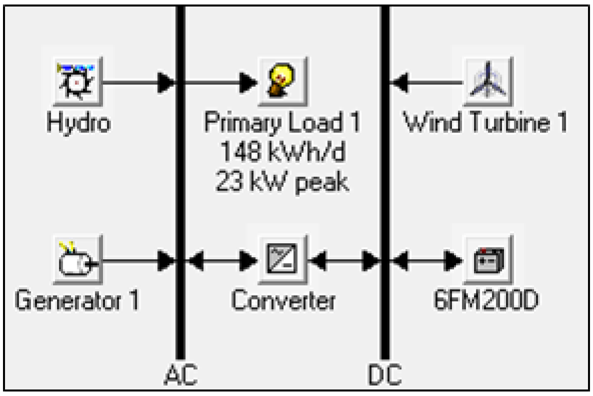


Fig.8. Schematic of the wind-hydro-DG system

Table 6. Brief summary of wind-hydro-DG system with $ 0.9/L diesel cost and 188 L/s flow rate

	148 kWh/d	200 kWh/d	250 kWh/d
Total net present cost	$ 249,506	$275,292	$333,435
Levelized cost of energy	$ 0.361/kWh	$0.295/kWh	$0.286/kWh
Operating cost	$ 12,485/yr	$14,111/yr	$17,408/yr
Diesel consumption	3535 litres/yr	4471 litres/yr	5477 litres/yr

D. Hydro-DG system (Model- IV)

The schematic of this model is shown in Fig.9 while the brief summary of result is presented in Table 7. It was found that the operating cost increases from $12,367/yr to $17,408/yr as the load increases from 148 to 250 kWh/day and this may be due to higher amount of diesel consumption at higher loads. However, the COE decreased from $0.357 to

$0.283/kWh as the load increased from 148 to 250 kWh/day. Also the diesel consumption increases from 3542 litres to 5484 litres as the load increases from 148 to 250 kWh/d. This system with proposed configuration will also not support the load of 300 kWh/d.

On the basis of cost of energy, it was found that hydro DG system (System IV) has the minimum COE ($ 0.357/kWh) at all three levels of loads while solar-wind-hydro-DG system has the highest COE($ 0.375/kWh) at the same three levels of loads. In general, COE decreases with increase in loads for all the models. With the proposed configuration, no system can supply the loads of 300 kWh/d. Minimum CO_2 will be produced in solar-wind-hydro-DG system while highest CO_2 will be released by hydro-DG system (Table 8).

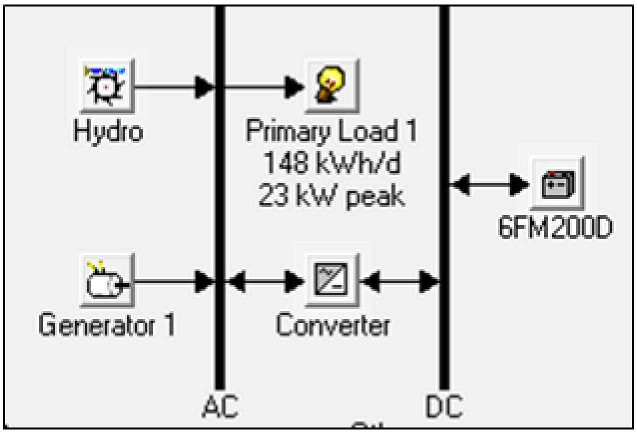


Fig. 9. Schematic of the hydro-DG system

Table 7. Brief summary of hydro-DG system with $ 0.9/L diesel cost and 188 L/s flow rate

	148 kWh/d	200 kWh/d	250 kWh/d
Total net present cost	$ 246,295	$272,083	$330,210
Levelized cost of energy	$ 0.357/kWh	$0.292/kWh	$0.283/kWh
Operating cost	$ 12,367/yr	$13,993/yr	$17,408/yr
Diesel consumption	3542 litres/yr	4478 litres/yr	5484 litres/yr

Table 8. Cost summary of different systems with CO_2 production at 148 kWh/d load

	NPC, $	Operating cost, $/ yr	COE, $/kWh	CO_2 production, kg/yr
Solar-wind-hydro-DG system	258615	12416	0.375	8866
Solar-hydro-DG system	255411	12298	0.370	8885
Wind-hydro-DG system	249506	12485	0.361	9309
Hydro-DG system	246295	12367	0.357	9327

2. Conclusion

Taking in to consideration of the load profile of the village, different configuration of equipments were analysed through HOMER and it was found that, least cost of energy ($ 0.357/kWh) with lowest NPC($246,295) was observed with hydro-DG system. The highest cost of energy ($0.375/kWh) with highest NPC ($258,615) was observed with solar-wind-hydro- DG system. Higher rate of CO_2 production to the tune of 9327 kg/yr is observed with hydro-DG system. At present load condition (148 kWh/day), though COE of solar-wind-hydro-DG system (model- I) is $0.018/kWh higher than that of hydro-DG system, minimum CO_2 (8866 kg/yr) is produced in this system. Looking in to CO_2 production and future load demand, solar-wind-hydro-DG system (system I) can be recommended for installation at the site.

References

[1] Ross M, Hidalgo R, Abbey C, Jeos G.(2010). Analysis of energy storage sizing and technologies. *Electric Power and Energy Conference (EPEC), IEEE* , pp.1-6, 25-27.

[2] Moniruzzaman Md, Samiul H. (2012). Cost analysis of PV/ Wind/Diesel/Grid connected hybrid systems. *IEEE/OSA/IAPR International Conference on Informatics, Electronics & Vision*, IEEE, pp 727-730.

[3] Badawe EM, Iqbal T, George M.(2011). Optimal sizing and modelling of a hybrid energy system for a remote telecommunication facility. A paper presented at IEEE 21, NECEC Conference, St John's NF.

[4] Anonymus, (2012). Achievement of OREDA up to 2011-12, Odisha Renewable Energy Development Agency, Bhubaneswar, India.

[5] http://eosweb.larc.nasa.gov/sse

[6] Ahmad R, Kazem M, Hossein K.(2010). Modeling of a hybrid power system for economic analysis and environmental impact in HOMER. Proceedings of ICEE .

[7] Gang L, Rasul MG, Amanullah MTO, Khan, MMK.(2011). Feasibility study of stand-alone PV-wind-biomass hybrid energy system in Australia. *IEEE*.

[8] Muralikrishna M, Lakshminarayana V.(2008). Hybrid (solar and wind) energy systems for rural electrification. *ARPN Journal of Engineering and Applied Sciences*. Vol. 3, No. 5.

[9] Mohammad SA, David WG. (2007). Modelling and analysis of a wind/PV/fuel cell hybrid power system in HOMER, *IEEE*, pp. 1594-1599.

[10] Abha Rajoriya, Eugene Fernandez,2013. Hybrid energy system size optimization and sensitivity evaluation for sustainable supply in a remote region in India, International Journal of Sustainable Energy , Vol 32, Issue 1, pp.27-41.

[11] A. H. Al-Badi, M. AL-Toobi, S. AL-Harthy, Z. Al-Hosni, A. AL-Harthy, 2012. Hybrid systems for decentralized power generation in Oman, International Journal of Sustainable Energy, Vol. 31, Issue 6, pp 411-421.

[12] Anis Afzal, Mohibullah Mohibullah & Virendra Kumar Sharma, 2010. Optimal hybrid renewable energy systems for energy security: a comparative study, International Journal of Sustainable Energy , Vol. 21, Issue 1, pp 48-58.

[13] Bindu U Kansara and B.R. Parekh, 2011. Modelling and Simulation of Distributed Generation System Using HOMER Software, International Conference on Recent Advancements in Electrical, Electronics and Control Engineering,, IEEE, p-328-332.

[14] http://oredaodisha.com/success.htm

[15] http://oredaodisha.com/achievements.htm

[16] http://eai.in/club/users/

[17] http://scribed.com/doc/57983815/solar-wind-hybrid system

[18] http://ibexenergy.in/about-us/

[19] http://ieeexplore.ieee.org/xpls/abs

[20] http://ijmra.us/2013ijmie_january.php