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Standalone Hybrid Power System for a Rural Destination in India: An Economic Analysis

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***Abstract*—** Demand of energy in isolated parts of India is solved by extension of grid power supply but it is not economical at all as cost varies depending upon distance,land and load demand.In view of this problem,supply of power to remote area demands advanced skill with updated technical and economical strategies.Because of that expensive and insufficient grid power in rural places have been replaced by renewable energy sources.So this particular work chooses the best hybrid technology for rural electric generation for a village area in Bhubaneswar. The solution obtained from using HOMER software presents the economic feasibility of the hybrid generation system for a rural conglomerate in Ghatikia, Bhubaneswar with latitude 20.26 ^{0} N and longitude 85.76 ^{0}E.This paper contains four different type of Hybrid configuration. The optimization result obtained by using a hybrid configuration composed of a wind energy system, a solar PV system and a diesel generator used as a backup system.

***Keywords*—**HOMER,Microgrid,TechnoEconomicAnalysis

I. INTRODUCTION

It is always challenging to supply power to the rural isolated places situated far away from the main grid. [1]. There are lots of reason like distance from regional and main grid,difficult terrain like jungles,mountains,harsh weather condition which possess hinderance in supply of electricity to the rural places [2–4]. Setting up of power plants[5] for rural electrification depend upon certain criteria like place,terrain,availability of natural resources[6–9],drid availability,DG,LPG,storage devices, biomass technologies etc.Grid extension has been the predominant mode of rural electrification but depends upon the distance of the places from the grid[10].Rural electrification has become an important part socially and economically for the overall growth and development of India[13]. Rural off grid electrification provides an alternative solution that reduces environmental impact and costs in comparison to conventional conventional grid.

The main of this work to discuss the tehno economic analysis of standalone power systems and their contribution to rural electrification in a sustainable manner.Ghatikia, once upon a time considered as a remote rural village is situated in the peripheral boundary of the city of Bhubaneswar having latitude 20.26 ^{0} N and Longitude 85.76 ^{0}E.The place is surrounded by forest reserve area like chandaka at one side and a famous tourist place Khandagiri at other.Though the place is situated near the Grid,alternative hybrid energy sources like PV,Wind will deffinitely make the villagers self reliable and self sustainable.Bhubaneswar gets an average solar radiation equals to 4.82 kilo watt hour/m ^{2} /day.Remote place like Ghatikia does nt get wind power during all the time and solar energy is absent during night hour.These palces need hybrid form of energy with a combination of both solar and wind.HOMER micro power optimization model gives a simplified solution for both isolated and grid connected power systems. HOMER gets its inputs describing the technology options ,component costs and resource availability[1].Further these inputs have been used by HOMER for simulating different system configurations or combination of different components.HOMER produces several solutions indicating the net present cost(NPC) and cost of energy(COE).For a case study ,a small conglomeration in rural village has been considered for techno economic analysis.

Generally Grid extension is impractical and quite expensive.The cost of fuel price is also increasing drastically for the last five years.Proper evaluation of economic feasibility of hybrid power source is essential in order to mitigate the energy shortage crisis.HOMER plays a crucial role in analysing the cost effectiveness of a hybrid power system.HOMER (Hybrid Optimization Model for Electric Renewable) has been developed by National Renewable Energy Laboratory (NREL) in the United States .Sharma et al [2] have conceptualised a Optimized PV-Solar and Wind hybrid power system in the village of Imaliya (Bhanpur) based on input solar radiation and hourly wind speed.Four different input variables such as wind speed,solar radiation,load and diesel price have been considered in order to get optimum result. The best Optimal Combination of Energy System Component is Two 7.5kw BWC-Excel-R, 1 KW PV-Array and 2 00.500 KW Diesel Generator. The total Net Present Cost (NPC), Capital Cost and Cost Of Energy (COE) obtained for such a System Is $112174,$ 59400 and 0.692$/Kwh, respectively.J. B. Fulzele , Subroto Dutt [3] have devised a method for optimum planning of hybrid renewable energy based power system.HOMER based software has been used to analyse and simulate the system configuration.Sensitivity analysis is carried out to judge the performance of different components of system.From the results it becomes evident that solar PV generator with battery and inverter prove to be most economical alternative than PV-Wind-Battery set up as total net present cost and cost of electricity are minimum.

The paper is divided into 4 parts.Part I of the paper is the introductory part while part II discusses the related literatures .Different combination of renewable energy sources have been thoroughly discussed in part III.Part IV discusses the simulation part followed by the conclusion part in part V.

II.**DETAILED LITERATURE WORK**

HOMER software has been used by Rachit Srivastava and Vinod Kumar Giri [4] for optimization of renewable energy sources in Electrical Engineering department laboratory in MM Malviya University of technology, India.System performance including sensitivity analysis have been carried out at different operating conditions.Optimum results have been found out with a configuration having 5 Kilo watt PV panel,4 KW generator and 10 batteries. Further this software has been used by Deepak et al. [5] for designing a hybrid renewable power system model for modelling and simulating renewable energy system in rural areas of Sundargarh, Odisha.From the simulation results, cost of energy(COE) involved in the proposed method is found to be higher than conventional energy sources. S.Salehin et al.[6] have discussed the application of techno-economic feasibility study of solar-diesel mini grid system in north part of Bangladesh. Diesel price as well as solar irradiation has been used as sensitivity variables. Further by the use of sensitivity inputs, the proposed hybrid renewable energy system has been compared with a diesel generator based energy system. COE of Solar-diesel system comes $0.038 more than the diesel generator as shown in Figure.1. COE in HOMER is defined as the average cost/kWh of useful electrical energy produced by the system.The equation for the COE is mentioned as $$COE = \frac{C_{annual}}{E_{primaryAC} + E_{primaryDC} + E_{grid}}$$

General Survey has been done to know the information of energy consumed per day in the rural area considered for case study. 122 houses are leaving in this village. On an average one unit (house) has three bulb (100 W each), one fan (150 W). Details about the village briefly described below.

Figure.1.Map details of Khandagiri (Ghatikia)

Table 1.Village Description

Description about Village	
Village	Ghatikia Bhubaneswar
Latitude	20.26 ^{0} N
Longitude	85.76 ^{0}E
Solar Insolation	4.76 kWh/m2/day
Wind speed	3.98m/sec
No of houses Considered	122
Average family member	5
No of Population	610

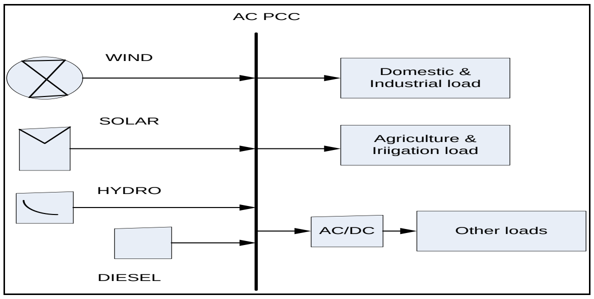


Figure.2.Block diagram of a Hybrid power system.

HOMER finds out the average daily consumption of system depending on the outlined power profiles.This paper contains a load detail for different configuration of the village Ghatikia,selected as a case study(Table.1). A primary load of 366.20 kWh/day having 45.41 peak loads is taken for simulation. Fig 4.(a) Daily and Figure.4.(b) Seasonal load details.Fig 4.(c).stands for yearly profile load data.

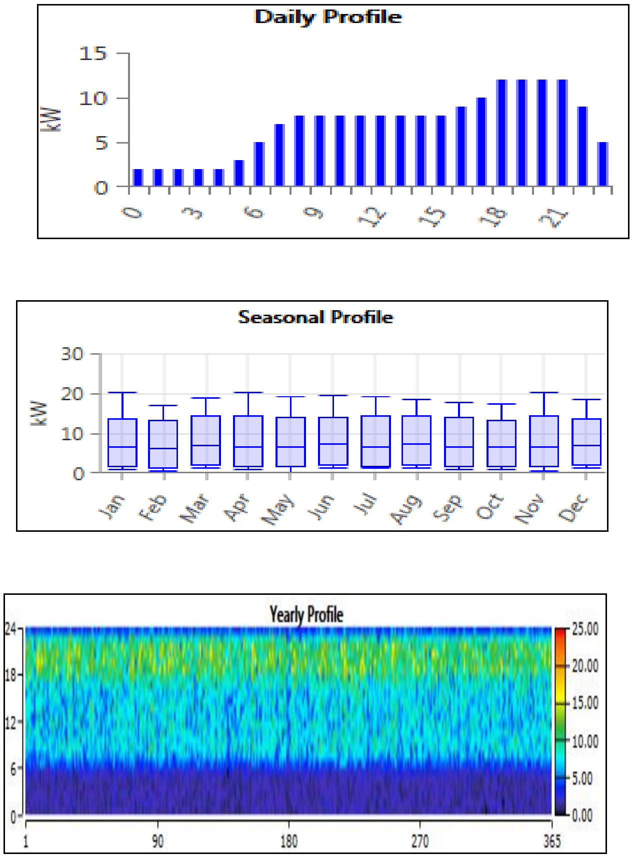


Figure.3. a) Daily profile b) Seasonal profile c) Yearly profile of load data

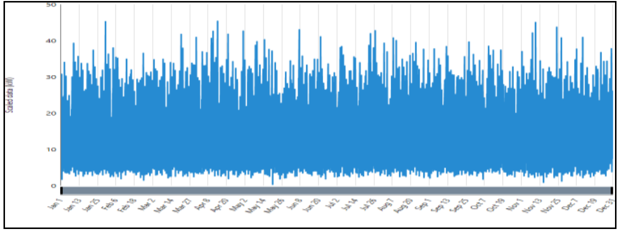


Figure.4.Yearly profile of Scaled data

III. SYSTEM CONFIGURATION OF DIFFERENT CASES

Wind&solar data are collected using NASA surface meteorology database (http://eosweb.larc.nasa.gov/) having the wind direction at 25 meters above the surface of the earth). Database gives the monthly average wind speed data for a period of 22 years (July 1983-june2005). All locations do not happen to be suitable for effective wind turbines and therefore annual average wind speed is taken as indicator for determining suitability of a place for a wind turbine(Fig.5). Detailed information for this particular site having latitude 20.26 ^{0} N and Longitude 85.76 ^{0}E are downloaded from NASA website for further analysis(Fig.6).

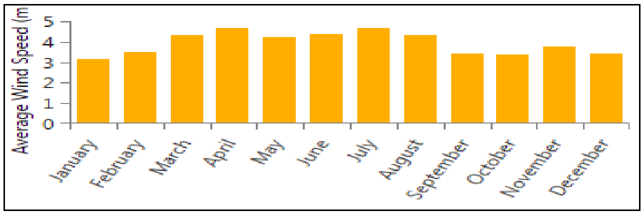


Figure.5. Monthly Average Wind speed

Solar data gets imported by HOMER from NASA surface meteorology database by entering latitude and longitude. Using the coordinates the annual solar radiation of this area is 4.82 kWh/m2/d as shown in Fig.7.

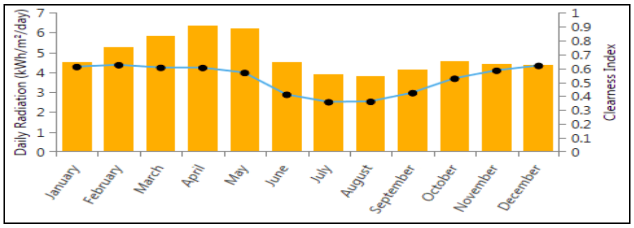


Figure.6. monthly average solar radiation & clearness index

For detailed analysis, four cases have been considered where the system configurations get evaluated by the use of HOMER (Hybrid Optimization model for energy Resource Version 3.6.1).Simulation outcome projects different configuration of renewable sources with comparative analysis in terms of system design,capital cost,maintenance cost,salvage,fuel(Fig.8).

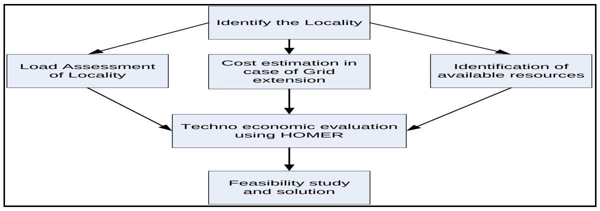


Figure.7.Detailed working of HOMER software

In case of the first model(case 1) as shown in Fig.9,the battery has been connected to the DC terminal, generator is connected to the AC terminal and the converter is attached to AC and DC bus bars.Load profile has been a maximum load of about 366.20 kWh/d. HOMER calculates the system and operating cost by simulating the load profile and making energy balance calculation for 8,760 hours in one year.In

Fig.[10-11] the model has been represented with a PV based generation unit having same amount of load connected. Improvement is seen in the system by the addition of wind based system as shown in Fig.12.

i) **Case I**

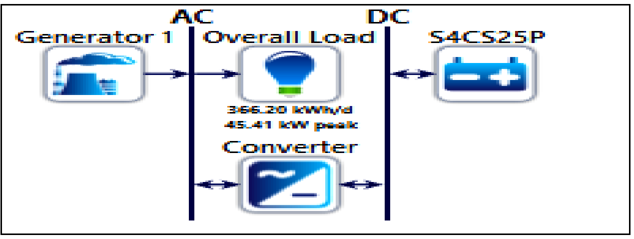


Figure.8.schematic representation of diesel power plant

ii)

Case II

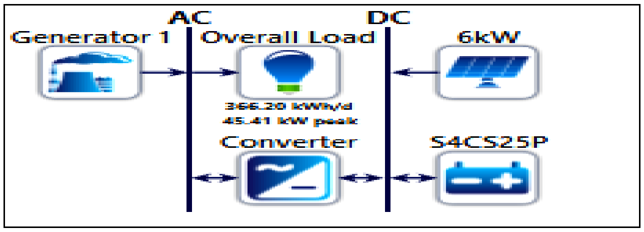


Figure.9.Schematic representation of (pv-diesel) power system

iii) **Case III**

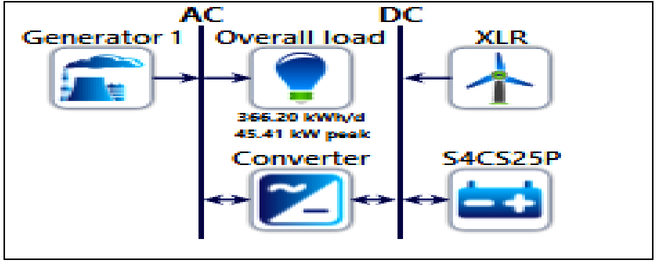


Figure.10.schematic representation for (wind-diesel) hybrid model

iv) **Case IV**

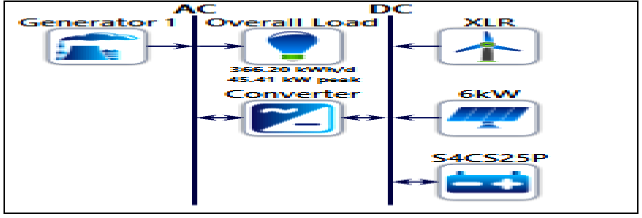
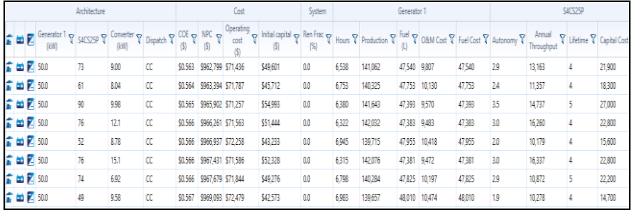


Figure.11.schematic representation of (pv-wind-diesel) hybrid power system model

IV. SIMULATION RESULTS

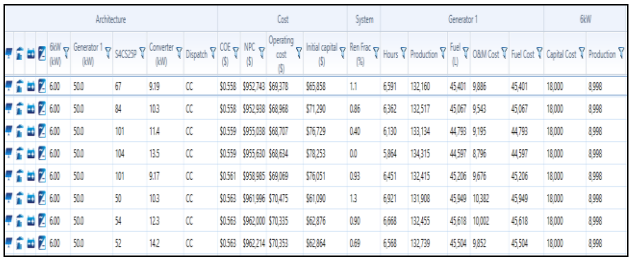
Through HOMER optimal system configuration is found out.Four different configurations and its simulation results have been presented. Optimum combination of different renewable energy sources with cost analysis have been speculated with this advanced software HOMER.

Table II. Optimal solution for DIESEL power system



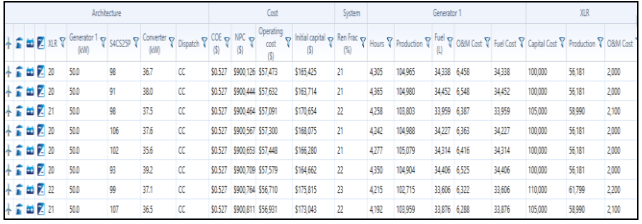
Architecture				Cost				System	Generator 1					S4CS25P			
Generator 1 (kW)	S4CS25P	Converter (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($)	Initial capital ($)	Ren Frac (%)	Hours	Production	Fuel (L)	O&M Cost	Fuel Cost	Autonomy	Annual Throughput	Lifetime	Capital Cost
50.0	73	9.00	CC	$0.563	$962,799	$71,436	$49,601	0.0	6,538	141,062	47,540	9,807	47,540	2.9	13,163	4	21,900
50.0	61	8.04	CC	$0.564	$963,394	$71,787	$45,712	0.0	6,753	140,325	47,753	10,130	47,753	2.4	11,357	4	18,300
50.0	90	9.98	CC	$0.565	$965,902	$71,257	$54,993	0.0	6,380	141,643	47,393	9,570	47,393	3.5	14,737	5	27,000
50.0	76	12.1	CC	$0.566	$966,261	$71,563	$51,444	0.0	6,322	142,032	47,383	9,483	47,383	3.0	16,260	4	22,800
50.0	52	8.78	CC	$0.566	$966,937	$72,258	$43,233	0.0	6,945	139,715	47,955	10,418	47,955	2.0	10,179	4	15,600
50.0	76	15.1	CC	$0.566	$967,431	$71,586	$52,328	0.0	6,315	142,076	47,381	9,472	47,381	3.0	16,337	4	22,800
50.0	74	6.92	CC	$0.566	$967,679	$71,844	$49,276	0.0	6,798	140,284	47,825	10,197	47,825	2.9	10,872	5	22,200
50.0	49	9.58	CC	$0.567	$969,093	$72,479	$42,573	0.0	6,983	139,657	48,010	10,474	48,010	1.9	10,278	4	14,700

Table III Optimal solution for DIESEL with PV power system



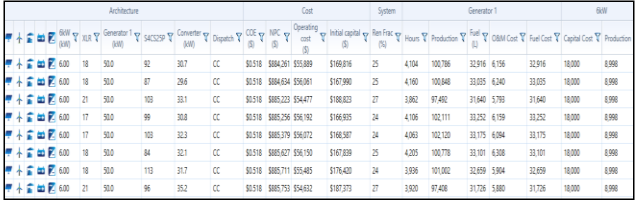
Architecture					Cost				System	Generator 1					6kW	
6kW (kW)	Generator 1 (kW)	S4CS25P	Converter (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($)	Initial capital ($)	Ren Frac (%)	Hours	Production	Fuel (L)	O&M Cost	Fuel Cost	Capital Cost	Production
6.00	50.0	67	9.19	CC	$0.558	$952,743	$69,378	$65,858	1.1	6,591	132,160	45,401	9,886	45,401	18,000	8,998
6.00	50.0	84	10.3	CC	$0.558	$952,938	$68,968	$71,290	0.86	6,362	132,517	45,067	9,543	45,067	18,000	8,998
6.00	50.0	101	11.4	CC	$0.559	$955,038	$68,707	$76,729	0.40	6,130	133,134	44,793	9,195	44,793	18,000	8,998
6.00	50.0	104	13.5	CC	$0.559	$955,630	$68,634	$78,253	0.0	5,864	134,315	44,597	8,796	44,597	18,000	8,998
6.00	50.0	101	9.17	CC	$0.561	$958,985	$69,069	$76,051	0.93	6,451	132,415	45,206	9,676	45,206	18,000	8,998
6.00	50.0	50	10.3	CC	$0.563	$961,996	$70,475	$61,090	1.3	6,921	131,908	45,949	10,382	45,949	18,000	8,998
6.00	50.0	54	12.3	CC	$0.563	$962,000	$70,335	$62,876	0.90	6,668	132,455	45,618	10,002	45,618	18,000	8,998
6.00	50.0	52	14.2	CC	$0.563	$962,214	$70,353	$62,864	0.69	6,568	132,739	45,504	9,852	45,504	18,000	8,998

Table IV. Optimal solution for DIESEL with WIND system



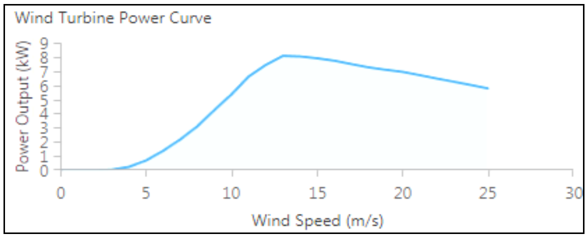
Architecture					Cost				System	Generator 1					XLR		
XLR	Generator 1 (kW)	S4CS25P	Converter (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($)	Initial capital ($)	Ren Frac (%)	Hours	Production	Fuel (L)	O&M Cost	Fuel Cost	Capital Cost	Production	O&M Cost
20	50.0	98	36.7	CC	$0.527	$900,126	$57,473	$165,425	21	4,305	104,965	34,338	6,458	34,338	100,000	56,181	2,000
20	50.0	91	38.0	CC	$0.527	$900,444	$57,632	$163,714	21	4,365	104,980	34,452	6,548	34,452	100,000	56,181	2,000
21	50.0	98	37.5	CC	$0.527	$900,464	$57,091	$170,654	22	4,258	103,803	33,959	6,387	33,959	105,000	58,990	2,100
20	50.0	106	37.6	CC	$0.527	$900,567	$57,300	$168,075	21	4,242	104,988	34,227	6,363	34,227	100,000	56,181	2,000
20	50.0	102	35.6	CC	$0.527	$900,653	$57,448	$166,280	21	4,277	105,079	34,314	6,416	34,314	100,000	56,181	2,000
20	50.0	93	39.2	CC	$0.527	$900,709	$57,579	$164,662	22	4,350	104,904	34,406	6,525	34,406	100,000	56,181	2,000
22	50.0	99	37.1	CC	$0.527	$900,764	$56,710	$175,815	23	4,215	102,715	33,606	6,322	33,606	110,000	61,799	2,200
21	50.0	107	36.5	CC	$0.527	$900,811	$56,931	$173,043	22	4,192	103,959	33,876	6,288	33,876	105,000	58,990	2,100

Table V. Optimal solution for Hybrid PV-WIND-DIESEL power system



Architecture						Cost				System	Generator 1					6kW	
6kW (kW)	XLR	Generator 1 (kW)	S4CS25P	Converter (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($)	Initial capital ($)	Ren Frac (%)	Hours	Production	Fuel (L)	O&M Cost	Fuel Cost	Capital Cost	Production
6.00	18	50.0	92	30.7	CC	$0.518	$884,261	$55,889	$169,816	25	4,104	100,786	32,916	6,156	32,916	18,000	8,998
6.00	18	50.0	87	29.6	CC	$0.518	$884,634	$56,061	$167,990	25	4,160	100,848	33,035	6,240	33,035	18,000	8,998
6.00	21	50.0	103	33.1	CC	$0.518	$885,223	$54,477	$188,823	27	3,862	97,492	31,640	5,793	31,640	18,000	8,998
6.00	17	50.0	99	30.8	CC	$0.518	$885,256	$56,192	$166,935	24	4,106	102,111	33,252	6,159	33,252	18,000	8,998
6.00	17	50.0	103	32.3	CC	$0.518	$885,379	$56,072	$168,587	24	4,063	102,120	33,175	6,094	33,175	18,000	8,998
6.00	18	50.0	84	32.1	CC	$0.518	$885,627	$56,150	$167,839	25	4,205	100,778	33,101	6,308	33,101	18,000	8,998
6.00	18	50.0	113	31.7	CC	$0.518	$885,711	$55,485	$176,420	24	3,936	101,002	32,659	5,904	32,659	18,000	8,998
6.00	21	50.0	96	35.2	CC	$0.518	$885,753	$54,632	$187,373	27	3,920	97,408	31,726	5,880	31,726	18,000	8,998

The wind turbine power curve and cost curve are shown in Figure.12. and Figure.14.



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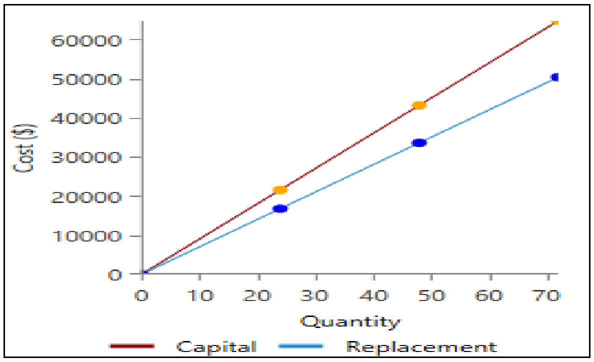


Figure.13. Power curve of wind turbine Fig.14. Cost curve of Wind Turbine

The fuel consumption curve and its efficiency is shown in Fig.15.

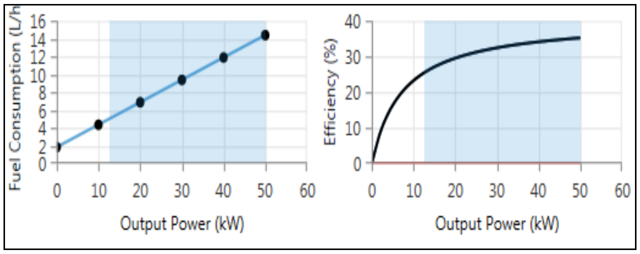


Figure.15.Fuel consumption curve and its efficiency

IV.A.Comparison of Optimal Solution and Economic Result

The System Configurations are evaluated by using HOMER (micro power optimization model).The results are calculated by using optimization and sensitivity analysis algorithms. For each system the system design costs are calculated. The system cost contains capital cost, replacement cost, operation and maintenance cost, Salvage and fuel cost. Here we considered four different types of configuration for comparison and estimation of lowest net present cost (NPC) with lowest Cost of Energy (COE).The Table VI.shows the Comparison of four different models with best optimum solution.

Simulation result shows the PV-Wind-Diesel model gives Lower Cost of Energy in comparison to other three configurations such as Diesel power system, Diesel with PV power system and Diesel with wind power system. As the Hybrid PV-Wind–Diesel power system gives lower Net present cost (NPC) and lowers Cost of Energy (COE) in comparison to other three configurations. So the hybrid PV-Wind-Diesel model is chosen as Energy and Economic analysis.

IV.B.ECONOMIC RESULT

HOMER software helps in conducting the energy balance calculation for each system configuration. It also helps in determining the feasibility of configuration and determines the stability of the system. The system is verified whether it handles the electric demand as per specification and estimates the economic status of the project.The system cost calculations account for costs such as capital, replacement, operation and maintenance, fuel, and interest. In the entire analysis process of the PV-Wind-Diesel Hybrid power system the detail information such as Cost Summary, Cost type, Cash flow summary, Monthly average Electric production, Fuel consumption and Total emissions are described below in Fig.(16-20).

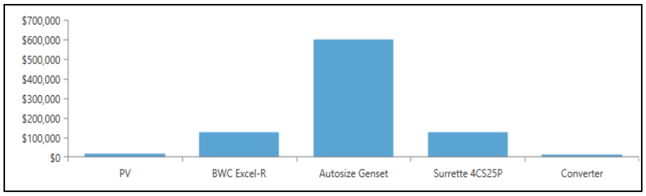
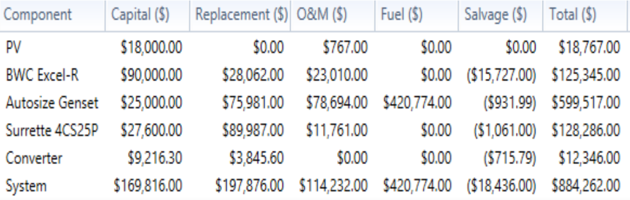


Figure.16. Cost summary



Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
PV	$18,000.00	$0.00	$767.00	$0.00	$0.00	$18,767.00
BWC Excel-R	$90,000.00	$28,062.00	$23,010.00	$0.00	($15,727.00)	$125,345.00
Autosize Genset	$25,000.00	$75,981.00	$78,694.00	$420,774.00	($931.99)	$599,517.00
Surrette 4CS25P	$27,600.00	$89,987.00	$11,761.00	$0.00	($1,061.00)	$128,286.00
Converter	$9,216.30	$3,845.60	$0.00	$0.00	($715.79)	$12,346.00
System	$169,816.00	$197,876.00	$114,232.00	$420,774.00	($18,436.00)	$884,262.00

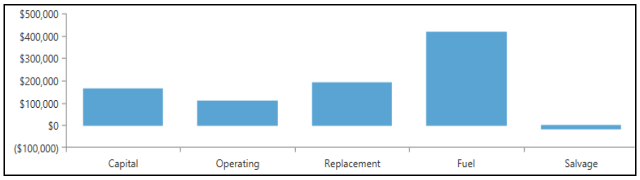


Figure.17. Cost type (P6)

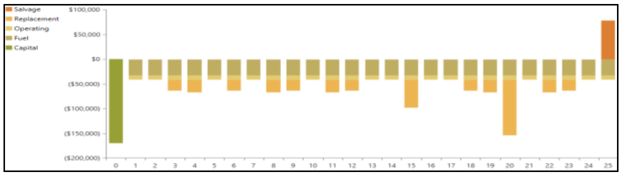


Figure.18. Cash flow summary (p6)

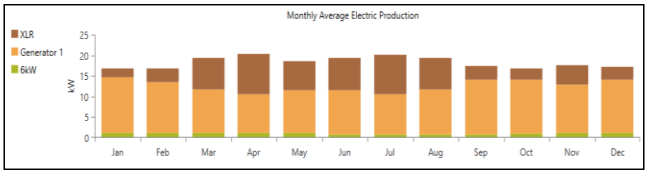


Figure. 19.Monthly average Electric production

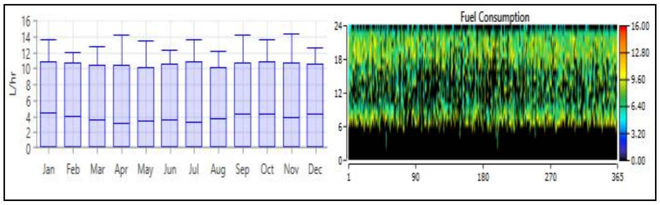


Figure. 20.Monthly average Fuel Consumption

Table VII. Fuel Consumption

Quantity	Value	Units
Total fuel consumed	32,916.00	L
Avg fuel per day	90.19	L/day
Avg fuel per hour	3.76	L/hour

Table VIII. Emissions after Comparison

Quantity	Value	Unit
Carbon dioxide	86,678.00	Kg/yr
Carbon Monoxide	213.95	Kg/yr
Unburned Hydro carbon	23.70	Kg/yr
Particulate matter	16.13	Kg/yr
Sulfur Dioxide	174.06	Kg/yr
Nitrogen Oxide	1909.10	Kg/yr

The HOMER software conducted the simulation within a small span of 15 second. The least COE of this system is found to be $0.117kWh. Renewable fraction of the optimum hybrid system has been 1 considering nil electricity purchase from the Grid.

V.CONCLUSION

Economic analysis has been done for the rural area considered in the paper. Four different hybrid configurations are considered and compared for this purpose. Simulation shows the configuration PV-WIND-DIESEL gives better result in comparison to other hybrid configuration. As the Hybrid PV-Wind–Diesel power system gives lower Net present cost (NPC) i.e. and lowers Cost of Energy (COE) i.e. in comparison to other three configurations. So the hybrid PV-Wind-Diesel model is chosen as Energy and Economic analysis. This paper recommends how the PV-WIND-DIESEL hybrid system increase the energy demand of the rural area considered for Case study.

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Appendix

a) Monthly Average Solar radiation (1983-2005)

Month	*Average radiation (kWatthour/m^2/d)*	*Clearness Index*
January	*4.53*	*0.608*
February	*5.26*	*0.622*
March	*5.82*	*0.603*
April	*6.34*	*0.602*
May	*6.18*	*0.566*
June	*4.50*	*0.409*
July	*3.88*	*0.356*
August	*3.80*	*0.359*
September	*4.15*	*0.421*
October	*4.57*	*0.524*
November	*4.43*	*0.581*
December	*4.38*	*0.616*

b) Monthly average Wind speed (1983-2005)

month	*wind Speed(m/sec)*
January	*3.15*
February	*3.48*
March	*4.32*
April	*4.68*
May	*4.24*
June	*4.37*
July	*4.64*
August	*4.31*
September	*3.45*
October	*3.35*
November	*3.78*
December	*3.42*

c) Monthly average temperature (1983 – 2005)

Month	*Temperature*
January	*20.93*
February	*24.11*
March	*27.60*
April	*28.77*
May	*28.98*
June	*28.50*
July	*27.62*
August	*27.29*
September	*26.94*
October	*25.50*
November	*23.42*
December	*21.08*

Authors Profile

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