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Cost Analysis of Solar/Wind/Diesel Hybrid Energy Systems for Telecom Tower by Using HOMER

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Abstract- Hybrid energy systems such solar and wind energy in combination with diesel generator can be applied successfully in areas where grid connection is not available or considered uneconomical. Their costs can be minimized through proper equipment sizing and load matching. This study represents the cost analysis of various models of hybrid systems for powering a remote area telecom tower located at an island village Barakolikhola (Latitude $20^0$33’ N and Longitude $86^0$73’ E) of Kendrapara district of Odisha in India. 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 net present cost, operating cost per year and the energy cost/kWh for different models at the available resources were determined.

Keywords- Solar, Wind, Diesel, Hybrid Energy, Systems.

1. Introduction

Our country currently has about 4,00,000 telecom towers around the land and poised to increase to 4,50,000 shortly [1]. As a large number of towers are not connected to the grid or have access to reliable electricity, they have to install back up power systems for uninterrupted services. Diesel generators have been the choice of telecom operators in spite of their higher operating expenditure (OPEX) and carbon imprint. In India, Telecom Towers are estimated to burn about 2 Billion Liters of Diesel (around 500 million barrels) annually at a cost of $ 18,232 million [2]. On an average, about $ 4740 is being spent annually to fulfil the diesel requirements of a single telecom tower [3]. These high input costs also results in high pollution. The renewable energy ministry of Government of India had asked the telecom companies to reduce their dependency on conventional fuels and use alternative energy sources for partly powering their telecom towers. Indus Towers, the largest with over 1 lakh towers in India, planned to set up 2,500 solar towers by end of this year. Viom networks, which operates more than 38,000 towers across India, plans to run more than one fourth of this number on alternative energy within the next two years.

Each tower requires energy from 1000 W to 3000 W (older installation consumes more power as compared to new one because of technological advancement). Assuming average power consumption of each tower is 1200 W, then total CO_2 emission is 105.6 lakh tonne per hour by all these towers if we assume that all are running on state electricity [4]. In India about 70% telecom towers are in rural areas. Presently 40% power requirements are met by grid electricity and 60% by diesel generators [5]. The diesel generators are of 10-15 KVA capacity and consume about 3 litres of diesel per hour and produce 2.63 kg of CO_2 per litre. The telecom operator spends 3 billion INR (USD 67.42 million) every month towards running diesel generators in remote locations where grid base power is limited. This translates to an operational energy expense of around 65 billion INR annually to operate network towers, especially in off-grid locations [7]. Since, Electricity supply is erratic and is not available throughout the day in many parts, diesel generators (DG) are used to power the telecom network as a back up for power supply. DG’s are operational for 15-20 hours (avg.) in rural areas and 3- 7 hours in urban areas putting a stress on the environment by way of carbon emissions and noise pollution. For every kWh of grid electricity consumed, 0.84kg of CO_2 is emitted [6]. Total CO_2 emission is about 5 million tonnes due to diesel consumption and 8 million tonnes due to grid power per annum. Extensive use of DG has very adverse effects on environment as it emits higher amount of CO_2 and other GHG emission causing global warming. India has the fastest growing telecom network in the world with its high population and development potential. India's public sector telecom company BSNL (11.41%) is the 7th largest telecom company in the world. The dominant players in the market currently include Bharti-Airtel (20.09 per cent of the Indian market), Reliance Communications (16.70 %),

Vodafone (16.54 %), Tata Tele Services (11.08 %), Idea (10.97 %) and Aircel (6.76 %).

Abha R. and Fernandez E.[8] 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*. [9] 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 was suggested.

Afzal *et al.* [10] 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 which simplified the task of evaluating the design of an off-grid/standalone system. After simulating all possible system equipment with their sizes, a list of many possible configurations was suggested on the basis of net present cost.

Bindu and Parekh [11] 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. As wind speed increases, the penetration of PV and diesel reduces.

In this paper the simulation result of hybrid renewable energy system for off grid remote telecom application is analyzed by using HOMER and compared with “DG only” system.

HOMER, is the micro power optimization model which simplifies and designs both the off-grid and grid-connected power systems for a variety of applications. To design a power system, one must make many decisions about the configuration of the system i.e. what components does it make sense to include in the system design or how many and what size of each component should one use to make the design a feasible one. HOMER's optimization and sensitivity analysis algorithms make it easier to evaluate the many possible system configurations. To perform a sensitivity analysis, we have to provide sensitivity values that describe a range of resource availability and component costs. HOMER simulates each system configuration over the range of values by making energy balance calculations for each of the 8,760 hours in a year. For each hour, it compares the electric and thermal demand in the hour to the energy that the system can supply in that hour, and calculates the flows of energy to and from each component of the system and it then determines whether a configuration is feasible, i.e., whether it can meet the electric demand under the conditions that you specify, and estimates the cost of installing and operating the system over the lifetime of the project. After simulating all of the possible system configurations, it displays a list of configurations, sorted by net present cost (sometimes called lifecycle cost), that we can use to compare the system design options.

2. Present Architecture of Site

The basic component of the PV-wind-DG system that is installed in the telecom site is shown in Figure 1.

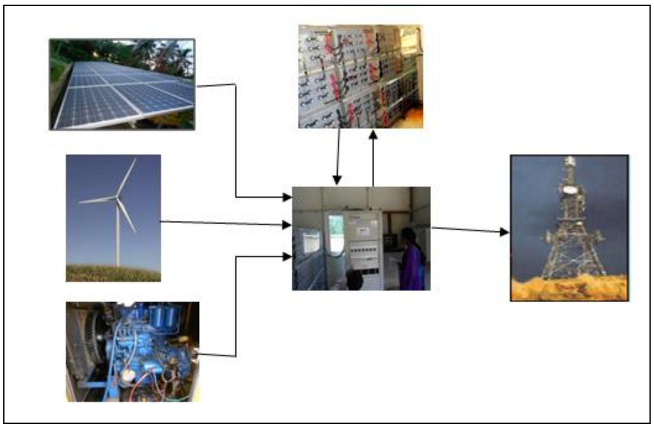


Fig 1. Components of solar-wind-DG system at the site

The electrical energy generated from PV-wind-DG system is fed directly to base trans-receiver station (BTS) load through the charge controller and battery unit. The energy that is stored in the battery is used to supply the power during low power production or at night when only wind turbine is functional. DG is used in the system as the secondary backup power supply as solar arrays and wind turbine are not the 100% reliable energy sources. DG can supply power when both solar-wind- battery systems fail to supply power to the load. As the load of the BTS is dc, but the DG and wind turbine produce ac, converter is used to convert ac to dc. It also regulates the power flow from each of the sources, acting as charge controller or boosting up the power. The details of the systems configuration used in the site including their cost, operation and maintenance cost (O&M) and lifetime are presented in Table-1.

Table 1. System equipment and their cost

Element	Sizes installed	Initial cost ($/kW)	Replacement cost, ($/kW)	O&M, ($/kW)	Life time (years)
Solar system	10 kW	4363	3927	0	20
Wind turbine	5.1 kW	1641	1477	82	20
Battery	48 nos, each of 2 V, 1250 Ah	268 (per unit)	268 (per unit)	13 (per unit)	8
Rectifier	6 kW	1000	1000	100	15
Inverter	6 kW	1000	1000	100	15
DG	16 kW	453	408	0.02 (per hour)	10 (15000 hrs)

2.1. Energy Resources for Hybrid Power System

For this hybrid system, the meteorological data of solar radiation and hourly wind speed were imported from NASA site. Figure 2 shows the variation of solar radiation and clearness index of the site. The average solar radiation of the site is 4.7 kWh/m2/day.

Wind speed also varies seasonally. Average wind speed of the area is 4.36 m/s. Figure 3 shows the monthly wind speed variation of the site.

Average energy consumption of the tower BTS is 23 kWh/d with a peak load demand of 2.0 kW. Figure 4 shows the hourly load pattern of the telecom tower.

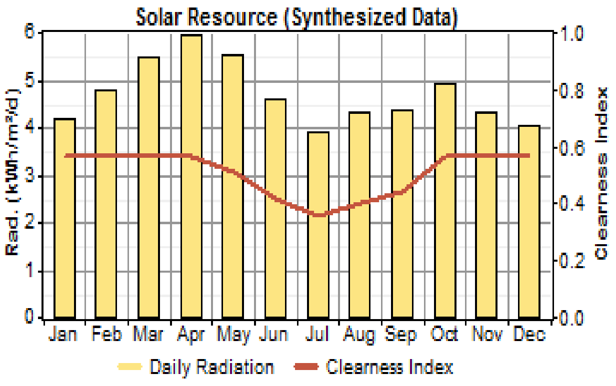


Fig. 2. Variation of solar radiation and clearness index of the site.

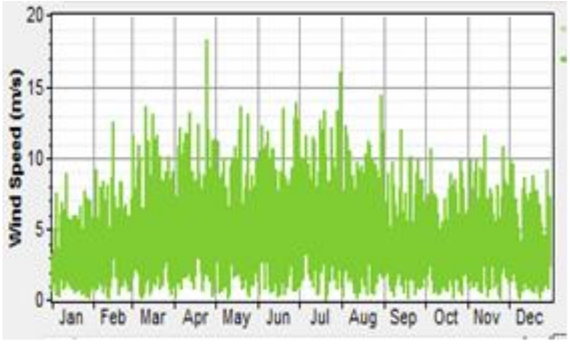


Fig. 3. Monthly wind speed variation of the site

Fig.4. Hourly load profile of the telecom tower site

2.2. System Analysis

For the analysis, salvage value of 10% (except battery) and O&M as 10% were taken. Actual cost of solar system, wind turbine, battery unit, DG was collected from the Executive Engineer, BSNL maintenance division, Cuttack .

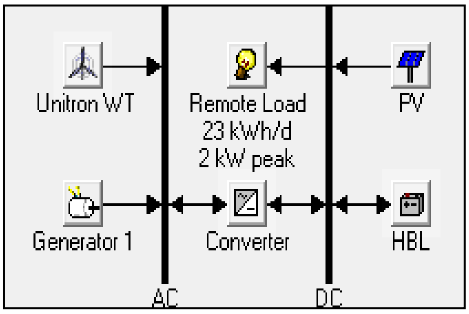
For simulation purposes, DG sizes of 8, 12 and 16 kW were selected. Similarly battery of 1 and 2 strings having 24 and 48 batteries were taken. The present load of the tower having 1 BTS is 22.7 kWh/d. (≈23 kWh/d). Another two loads of 55 and 83 kWh/d as calculated below were considered keeping in mind that in future, two more BTS will be commissioned at the site

.No of BTS	Power consumption/h	Power consumption/day
1	1.14 kW/h	27.36 kW (Actual av. 22.7 kW)
2	2.28 kW/h	55.0 kW
3	3.42 kW/h	83 kW

Similarly, different values of other variables like global radiation, wind speed and diesel price were taken for sensitivity analysis. Simulation results of various system configurations are presented below.

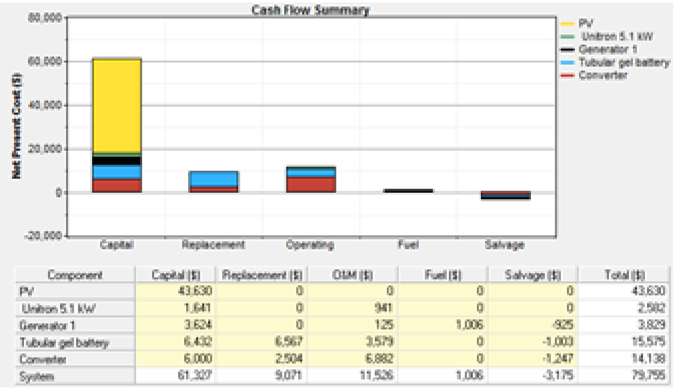
3. Solar-wind-DG system (System-I)

Solar PV (SPV) array of 10 kW, wind turbine (WT) of 5.1 kW, DG of 20 KVA capacity with 48 nos of tubular gel battery in two strings are installed at the telecom site. The system architecture is shown below.



System architecture of solar-wind-DG system

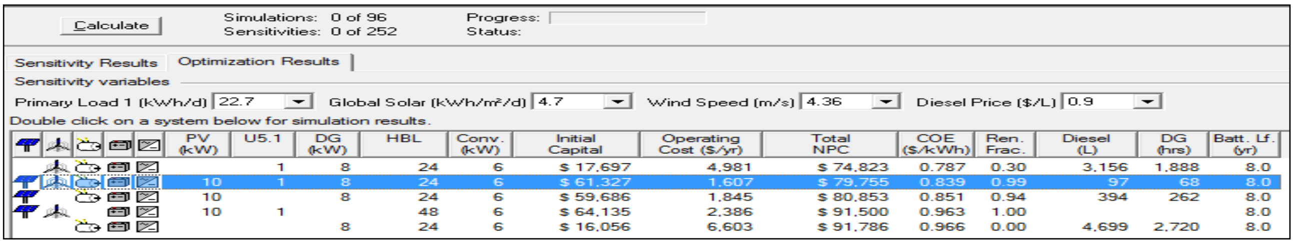
The component wise net present cost (NPC) of the system is shown in Figure 5 while the optimisation results at 22.7 kWh/d load, 4.7 kWh/m2/d of solar radiation, 4.36 m/s wind speed with diesel price of 0.9 USD per litre is shown in Figure 6.



Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
PV	43,630	0	0	0	0	43,630
Unitron 5.1 kW	1,641	0	941	0	0	2,582
Generator 1	3,624	0	125	1,006	-925	3,829
Tubular gel battery	6,432	6,567	3,579	0	-1,003	15,575
Converter	6,000	2,504	6,882	0	-1,247	14,138
System	61,327	9,071	11,526	1,006	-3,175	79,755

Fig. 5. Component wise net present cost (NPC) of the Solar -wind- DG system

The levelised cost of energy (COE) of solar-wind -DG system was found to be higher ($ 0.839/kWh) than wind-DG system at lower load of 22.7 kWh/d. But at higher load of 55 and 83 kW/h load, this model has the lowest cost of energy over all other systems (Table 2). The COE of this system varies from $0.839 to $0.506/kWh with annual diesel consumption ranging from 97 to 6752 litres as the load varies from 22.7 to 83 kWh/d. Excess electric energy production decreases from 45.2% to 1.10 % as load increases from 22.7 to 83 kWh/d . As load increases, COE decreases while the NPC and operating cost increases. Higher operating cost at higher loads may be due to higher amount of diesel consumption at higher loads.



Simulations: 0 of 96
Sensitivities: 0 of 252
Progress:
Status:

Sensitivity variables
Primary Load 1 (kWh/d) 22.7
Global Solar (kWh/m²/d) 4.7
Wind Speed (m/s) 4.36
Diesel Price ($/L) 0.9
Double click on a system below for simulation results.

PV (kW)	U5.1	DG (kW)	HBL	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)	Batt. Lf. (yr)
	1	8	24	6	$ 17,697	4,981	$ 74,823	0.787	0.30	3,156	1,888	8.0
10	1	8	24	6	$ 61,327	1,607	$ 79,755	0.839	0.99	97	68	8.0
10		8	24	6	$ 59,686	1,845	$ 80,853	0.851	0.94	394	262	8.0
10	1		48	6	$ 64,135	2,386	$ 91,500	0.963	1.00			8.0
		8	24	6	$ 16,056	6,603	$ 91,786	0.966	0.00	4,699	2,720	8.0

Fig. 6. Optimisation results of different systems

The NPC of this system varies from $ 79,755 to $175,725 as the load varies from 22.7 to 83 kWh/day. This may be due to expenditure of higher amount of operating cost at higher loads.

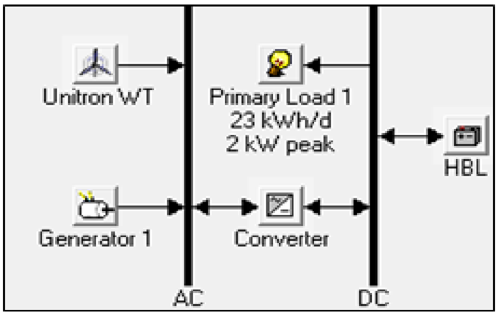
Optimized values of the components that were found out for this system were 10 kW Solar PV arrays, 24 batteries in a single strings, DG of 8 kW and 12 kW converter (6 kW inverter and 6 kW rectifier).

Table 2. Cost economics of various systems at different loads.

Systems	Parameters	Load, kWh/d		
		22.7	55	83
Solar-wind-DG	Cost of Energy (COE), $/kWh	0.839	0.552	0.506
	Net Present Cost, $	79,755	127,091	175,725
	Operating cost, $/year	1,607	5,173	9,413
	Excess electricity production/year, %	45.2%	2.73%	1.10%
Wind-DG	Cost of Energy (COE), $/kWh	0.787	0.590	0.536
	Net Present Cost, $	74,823	135,934	186,186
	Operating cost, $/year	4,981	10,308	14,129
	Excess electricity production/year, %	0.36	0	0
Solar-DG	Cost of Energy (COE), $/kWh	0.851	0.609	0.539
	Net Present Cost, $	80,853	140,213	187,285
	Operating cost, $/year	1845	6460	10564
	Excess electricity production/year, %	31.7	1.04	0.35
DG only	Cost of Energy (COE), $/kWh	0.966	0.648	0.568
	Net Present Cost, $	91,786	156,042	197,343
	Operating cost, $/year	6603	11,644	15,245
	Excess electricity production/year, %	0	0	0

4. Wind-DG system (System-II)

The system architecture is shown below.



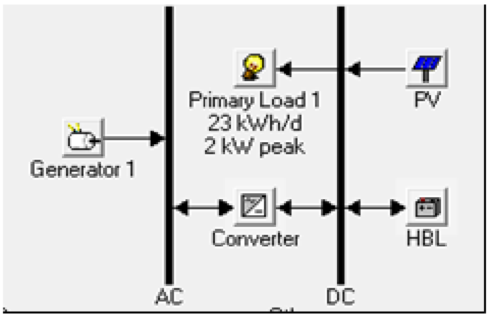
System architecture of wind-DG system

The lowest levelised cost of energy (COE) was found with wind -DG system ($ 0.787/kWh) at lower load of 22.7 kWh/d. But at higher load of 55 and 83 kW/h load, this model is less economical than solar-wind DG systems. The COE of this system varies from $0.787 to $0.536/kWh with annual diesel consumption ranging from 3156 to 11,403 litres as the load varies from 22.7 to 83 kWh/d (Table 2).

Excess electric energy production of 0.36 % was observed with this system at 22.7 kWh/d load but as the load increases, no excess electricity is available in the system. As load increases, COE decreases while the NPC and operating cost increases. Higher operating cost at higher loads may be due to higher amount of diesel consumption at higher loads.

5. Solar-DG system (System-III)

The system architecture is shown below.

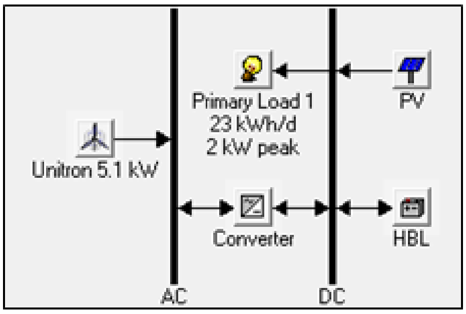


System architecture of solar-DG system

The levelised cost of energy (COE) of this system was found to be $ 0.851/kWh at lower load of 22.7 kWh/d. The COE of this system varies from $0.851 to $0.539/kWh with annual diesel consumption ranging from 394 to 7,932 litres as the load varies from 22.7 to 83 kWh/d (Table 2). Excess electric energy production decreases from 31.7 to 0.35% as the load increases from 22.7 to 83 kWh/d. As load increases, COE decreases while the NPC and operating cost increases. Higher operating cost at higher loads may be due to higher amount of diesel consumption at higher loads.

6. Solar-wind system (System-IV)

The system architecture is shown below.



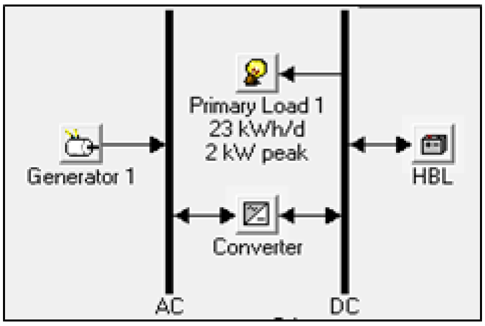
System architecture of solar-wind system

The levelised cost of energy (COE) of this system was found to be $ 0.963/kWh at lower load of 22.7 kWh/d. Excess electric energy production at this load is 44.6%. This configuration is not able to support the power requirement of telecom sites with 2 or 3 BTS having 55 and 83 kWh/d load respectively.

Cost economics

Total net present cost	$ 91,500
Levelized cost of energy	$ 0.963/kWh
Operating cost	$ 2,386/year
Excess electricity production	44.6%

7. DG system (System-V)



System architecture of DG system

The levelised cost of energy (COE) of this system was found to be $ 0.966/kWh at lower load of 22.7 kWh/d. The COE of this system varies from $0.966 to $0.568/kWh with annual diesel consumption ranging from 4699 to 12,551 litres as the load varies from 22.7 to 83 kWh/d (Table 2). As load increases, COE decreases while the NPC and operating cost increases. Higher operating cost at higher loads is due to higher amount of diesel consumption at higher loads.

The NPC of this system varies from $ 91,786 to $197, 343 as the load varies from 22.7 to 83 kWh/day. This may be due to higher amount of operating cost at higher loads.

2.3. Economic Analysis of Different Systems

Levelised cost of energy (COE) of different models is presented in Table 2 and Figure 7. It was found that the wind-DG system has the minimum cost of energy ($0.787/kW) at lower load. But as the load increases, COE of solar-wind-DG system decreases rapidly and at load 41 kWh/d, the wind-DG and solar-wind-DG line intersects. Loads above this threshold are best served by solar-wind-DG system. As the load increases, COE of solar wind-DG system further decreases i.e. the minimum COE were found with solar-wind-DG system at higher load of 55 ($0.552 /kW) and 83 kWh/d ($0.506/ kW) . In general, COE decreases with increase in load. The highest COE was observed with only DG system at all three levels of loads.

The solar-wind system (model IV) with the present configuration (Solar 10 kWp and wind turbine 5.1 kWp) can supply the energy need at lower load level of 22.7 kWh/d only. But as the load increases, this system will not able to support the higher loads

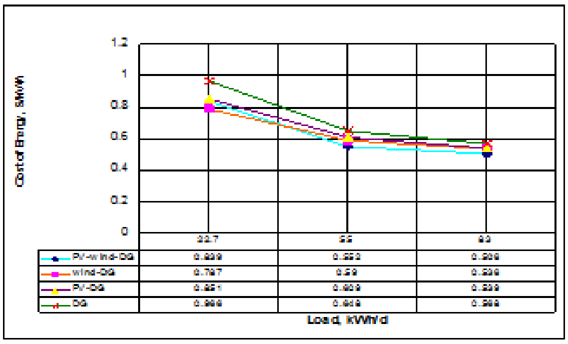


Fig. 7. Variation of COE with loads

The optimal system type (OST) graph of primary loads vs diesel price of the systems is presented in Figure 8. From the figure, it is seen that wind-DG system is not economical beyond the diesel price of $1.04 /L i. e. when diesel price increases more than $1.04 /L, solar-wind-DG system is economical.

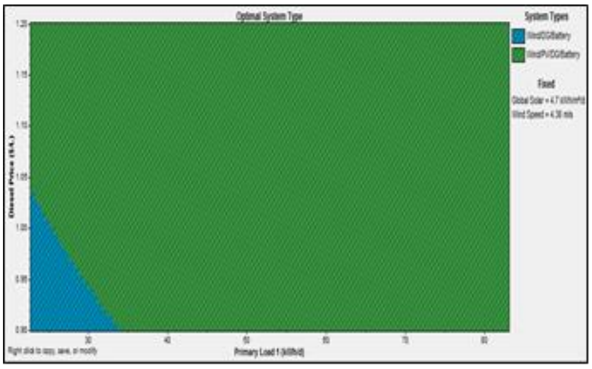


Fig. 8. OST graph of primary load vrs diesel price

The total net present cost (NPC) vs primary load is shown in Figure 9 where, the levelised cost of energy is superimposed. It is seen that, the NPC increases with increase in load for all the systems and this may be due to use of higher sizes of system configurations at higher loads. It is also seen that, the COE decreases sharply with increase in load up to 55 kWh/d and beyond that the COE decreases with load at lower rate. COE decreases sharply from the load 22.7 to 55 kWh/day due to the reason that, the COE depends upon the input cost and system sizing cost and for these two loads, system size remain the same while for higher loads system size and input cost changes at lower rates.

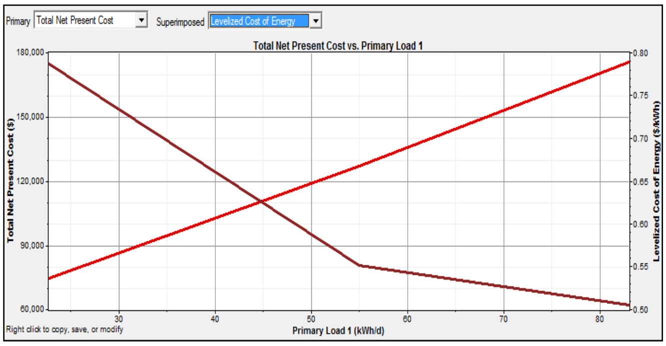


Fig. 9. Variation of Net Present Cost with change in loads

The variation of renewable components with loads is presented in Figure 10 from which it is seen that, the total electricity production increases with increase in loads while the electricity production by diesel generator does not vary much with increase in loads up to 55 kWh/d. Beyond 55 kWh/d load, the generator run hours increases with increase in loads. The area between these two lines represents the electricity production by renewable components which shows that with increase in loads, the electricity production by renewable components increases up to 55 kWh/d and thereafter, energy production by renewable components remains almost constant and diesel generator run hours increases to meet the energy requirements of the higher loads.

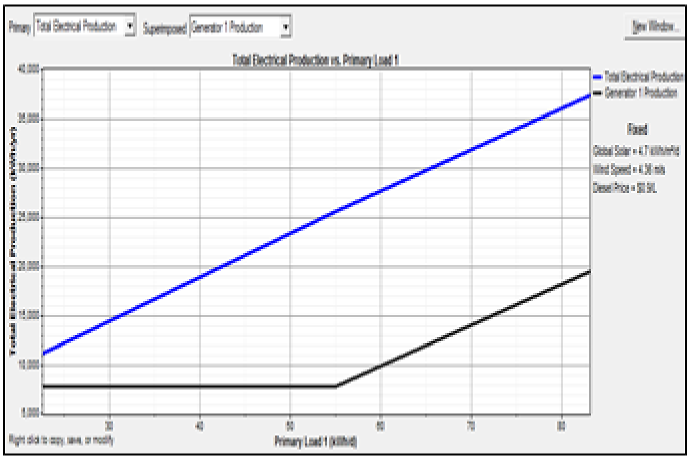


Fig. 10. Variation of renewable components with loads

3. Conclusion

For off-grid remote telecom tower, the hybrid systems having different combinations of energy resources were analysed by using HOMER software. The minimum COE was found with solar-wind-DG system at higher load of 55 ($0.552 /kW) and 83 kWh/d ($0.506/ kW) while at lower load of 22.7 kWh/d, wind-DG system has the minimum COE ($0.787/kW). In general, COE decreases with increase in load. The highest COE was observed with only DG system at all three levels of loads. The solar-wind system with the present configuration (Solar 10 kWp and wind turbine 5.1 kWp) can supply the energy need at lower load level of 22.7 kWh/d only at the COE of $ 0.963/kWh. But as the load increases, this system will not able to support the loads of tower equipment and require the solar-wind-DG system to run it. The feasibility study of the different models helped us to find the most appropriate and cost effective model to run the system.

Acknowledgements

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