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Hybrid System Analysis with Renewable Energy and Thermal Energy for Health Clinic – A Case Study

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***Abstract*— *This paper assessed optimal configurations of hybrid renewable system for health clinic in Jamshedpur. The clinic consists of doctor rooms, pharmacy, dressing room, pantry, day care and other equipment with average total daily energy consumption of 219.97kWh and 31.54kWpeak demand. The analysis is carried out by investigating the potentials of solar energy and collecting data from different sources. Hybrid Optimization Model for Electric Renewable (HOMER) software is used to analyse the available data and economic feasibility of the proposed hybrid power system, by considering two energy resources; photovoltaic (PV) and diesel with battery energy storage. The result obtained revealed hybrid PV/diesel/battery system as the most cost-effective configuration for powering health clinic. The selected optimal configuration is far better than the conventional diesel stand-alone system in terms of cost and emission reduction.*

I. INTRODUCTION

The use of conventional resources favours global warming, pollution, acid rains, gas emissions and alarm signals that warn that oil - the main source of transport fuels - is about to run out. Renewable energy sources (RES) offer an efficient solution to the global warming and high fuel cost. Therefore, there is a growing interest in RES, particularly photovoltaic (PV) and wind energy. Although wind and solar has several advantages, a solar or wind generator in a stand-alone system cannot supply the load continuously due to their intermittent nature. As load demands are always changing with time, the changes in solar or wind energy generations do not always match with the time distribution of consumer's demand. Therefore, there is a need of additional battery storage or other components for providing continuous power supply to the load. Recently, hybrid power systems using RE are becoming most popular due to their potential advantages. It has been investigated that a hybrid PV/Wind/battery system is a secure source of electricity. Although hybrid renewable energy systems are adopted, one of the challenges is to design an optimal energy management system to satisfies the load, taking into account the intermittent nature of these renewable energy sources and the variation in energy demand. The solar hybrid power system that operates out of its specification rate can lead to lowering the system efficiency and loss in financial. The system load and the capacity of available energy sources is important to highlight so that the hybrid power plants work more efficiently. In the hybrid energy system sizing plan, an accurate, reliable detail about the energy potential at a specific location is the most important thing.

II. METHODOLOGY

The simulated hybrid renewable energy system consists wind turbine, photovoltaic (PV) array with a power converter, battery and Diesel generator. The battery is added to the system as a backup unit and acts as a storage system. The system is designed by considering a health clinic. The solar resource data of the site was taken from online data of NASA Methodological department and National Renewable Energy Lab (NREL). The field survey has been conducted to get daily load profile and energy usage pattern of a health clinic for simulation. The HOMER software is used to determine the optimal sizing and operational strategy for a hybrid renewable energy system based on three principal tasks which are simulations, optimization and sensitivity analysis. The following subsection discusses the three principal tasks of the HOMER software.

Homer: Simulation

HOMER simulates the operation of the system based on the components chosen by the designer. In this process, HOMER will perform the energy balance calculation based on the system configuration consisting several numbers and sizes of the component. In this case study, PV array system, wind turbine, diesel generator with battery and converter are the components chosen for the analysis. HOMER simulates the system based on the estimation of installing cost, replacement cost, operation and maintenance cost, fuel and interest rate.

Homer: Optimization

The optimization process is based on the technical characteristics of the system and life cycle cost (LCC) of the system. HOMER display a list of configurations sorted based on the Total Net Present Cost (TNPC). It can be used to compare different types of system configuration from the lowest to the highest TNPC. However, the system configuration based TNPC is also affected by sensitivity variable.

Homer: Sensitivity Analysis

The HOMER software will repeat the optimization process for each sensitivity variables for the hybrid renewable energy system. The sensitivity variables here taken are such as fuel

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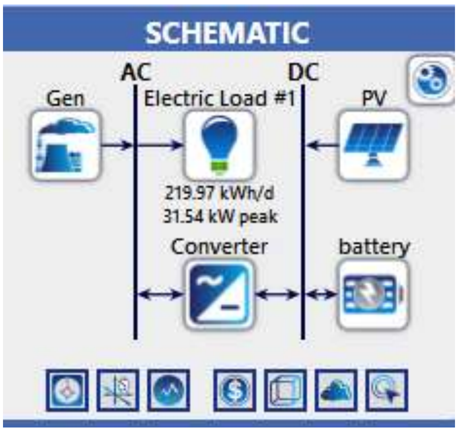
price and the electrical load, however, the global solar, wind speed etc. can be considered. After this TNPC of various configurations of hybrid renewable energy will be sorted from lowest to highest. Out of these, the lowest TNPC will be considered as the optimal solution.

III. SYSTEM CONFIGURATION

The hybrid renewable energy system includes PV system, battery units, diesel generator, power converter and electrical loads. Hybrid power generation systems can be classified into three kinds according to bus bar forms, including pure AC bus bar system, pure DC bus bar system and hybrid AC-DC bus bar system. In this study, AC-DC configuration is considered due to its advantage compared to other configurations.



Electrical Load Information

The load profile for the hybrid system was taken from the result of a survey of a health clinic. The daily load and hourly load was calculated. HOMER software needs hourly load as input for simulation. The case study dispensary consists of doctor rooms, pharmacy pantry, daycare and other medical equipment. The lifetime estimated for this project is 25 years in the simulation.

PV array

The size of a PV array system in the optimum system is 69kW. While the total capital cost is $156016.22 and there placement cost is zero since the project lifespan is the same as PV array lifetime, which is 25 years. The fixed PV panels will have a rated power of 12 kW per unit. The solar radiation data is taken from NASA meteorological department database. The lifetime for this PV array system is 25 years with a de-rating factor of 80% and ground reflectance is 20%.Fig 2 shows the average monthly solar radiation data at Jamshedpur where maximum radiation occurs in the month April and the minimum radiation available in the month of August, which is the raining season in the Indian subcontinent. It is seen from the data that the site has tremendous solar resource potential. This is the reason behind 96.7% of electrical energy come from the Photovoltaic array while the rest diesel generator in the optimum system.

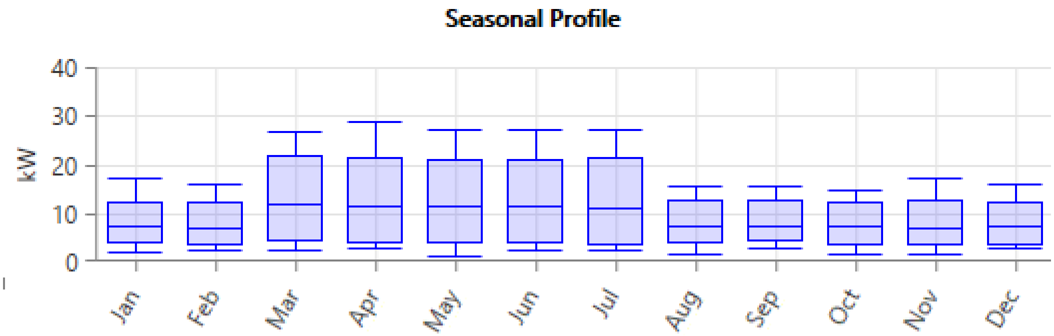


Fig. 1. Monthly load profile.

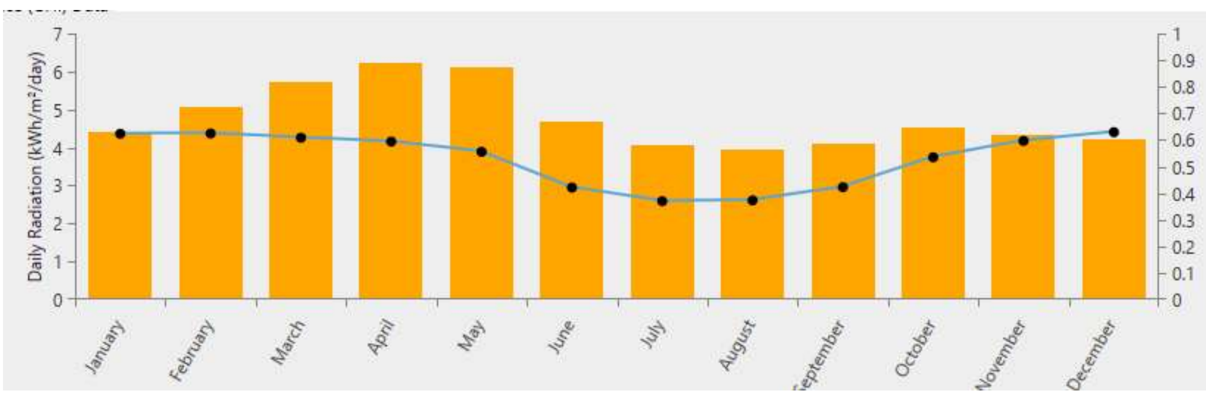


Fig. 2. Monthly average solar radiation.

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Diesel Generator

The diesel power plant of 35 kW is used in the optimal configuration. The diesel price with two discrete values of1$/L and 1.05$/L is used for the sensitivity variables. At present, the diesel price is about 1$/L in India. The lower heating value is 43.20 MJ/kg, the density of the fuel is820kg/m3 and carbon content is 88% and Sulphur content is0.40%. The emission rate of different pollutant per litre of fuel of the generator are such as CO 12.56g/L, particulate 0.718g/L, unburned HC 0.72 g/L, NOX 14.36 g/L are given in manufacturer sheet.

Battery

The type of battery that used for the system is 10 kWh model with the rating of 240 V, 41.7 Ah, with lifetime throughput 5,69,569 kWh. The cost for one battery is $270with the replacement cost of $270. Total of 38 batteries of10kWh capacities is used in the optimal system. The initial state of charging of all the batteries is 100%. The capital cost of batteries is $10,260 and replacement cost is$9,064because of life of the battery is 10 years only.

Power Converter

A power electronic converter is used to maintain the flow of energy between ac and dc component. The optimal size of power converter used in this system is of 31 kW. The capital cost and replacement costs for this equipment for a power converter is $3,717.32 and $1577.16respectively. The lifetime for one unit of the converter is 15 years with the efficiency of 95%.

Cost Details of All the Component

The capital cost, replacement cost, O&M cost, fuel cost, salvage cost and total cost is shown below.

TABLE 1. Cost details of all components.

Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
Autosize Genset	$7,000	$0.00	$5,309.48	$12,603.73	$-1,052.58	$23,860.63
Battery 10kWh	$10,60	$9,064.07	$0.00	$0.00	$-1,228.93	$18,095.14
Generic system converter	$3,717.32	$1,577.16	$0.00	$0.00	$-296.84	$4,997.64
PV Plate	$63,758.88	$0.00	$4,465.03	$0.00	$0.00	$68,3.91
System	$84,736.20	$10,641.23	$9,774.51	$12,603.73	$-2,578.35	$1,15,177.31

Operation Principle of Standalone Hybrid system

The operation principle of the proposed hybrid system is based on optimization of a simulated component of the hybrid power system. PV arrays are the primary load suppliers will charge the battery bank when there is an excess power remaining after meeting the load demand. The converter is used here to convert from DC to AC because PV output is in DC which need to be converted in AC power. There are two type of dispatch strategy on which HOMER work, one is cycling charging and another one is load following which is optimal depends on many factors, including the sizes of the generators and different component, the price of fuel, the O&M cost of the generators, the amount of renewable power in the system. Under the load following strategy, whenever a generator is needed it produces only enough power to meet the demand. Under load following strategy whenever generator has to operate it operate only enough to supply power demand with reduced capacity while under cyclic charging strategy whenever the generator has to operate, it operates at full capacity with surplus power going to charge the battery bank.

IV. Result and Discussion

Optimization of Hybrid Renewable Energy System without Considering Sensitivity Variables

The proposed hybrid renewable energy system for the village consists of the primary load of 219.97 kWh/day, with the peak load of 28.91kWh/day. The HOMER software identifies the best possible economical configuration for the hybrid renewable energy system. For an example, the optimal sizing and operational strategy for a hybrid renewable energy system may sometime consider all of the equipment or without considering one part of the equipment. Thus, the combination of the equipment is depending on the optimization procedure and sensitivity variables. Here three types of combination are found optimum after calculation by the HOMER. These are PV, DG and battery, PV with the battery and the last one is DG with battery. Out of three first combination is most optimum and having lowest NPC and COE value. All the three combinations are given in the following table 2 and it can be seen that top of the list has minimum $1,15,173 of NPC value. 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. Hence, multiple possible combinations of equipment could be obtained for the hybrid renewable energy system due to different size of PV array system, number of wind turbines, size of generator, number of batteries and size of dc-ac converter. The combination of system components is sorted from least TNPC to highest TNPC. The optimization results of hybrid renewable energy system are obtained for every selection of the sensitive case. The list of TNPC of different configuration without considering sensitivity variable like electrical load or fuel cost. The best (least) TNPC obtained here is $1,15,173 and cost of energy(COE) is$0.111/kWh with total renewable fraction is 96.7%.However, sensitivity variables are also taken for future uncertainty in calculation of TNPC. The price of fuel and variation in electrical load are taken as sensitive variable here.

Hybrid Renewable Energy System Considering Sensitivity Variables

There is two type of sensitivity variable are considered one is the Primary load which is 219.97 kWh/day and 240 kWh/day and another one is Diesel fuel price 1 $/L and 1.05

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$/L. The best configuration of hybrid renewable energy system consisting of the diesel generator, PV array system, battery storage and power converter with the total net present cost of $1,15,173 and cost of energy $0.111/kWh is obtained.

TABLE 2. Optimization result without considering sensitivity variable.

Combination of System				Architecture					Cost				
PV	DG	Battery	Converter	PV (kW)	DG (kW)	Battery (Units)	Conv (kW)	Dispatch	COE ($)	NPF ($)	Operating Cost($)	Initial Capital	Ren Frac (%)
PV	DG	Battery	Converter	69.1	35	38	31	LF	$0.11	$1,15,173	$2,354	$84,736	96.7
PV		Battery	Converter	92.3		67	39.7	CC	$0.13	$1,29,492	$1,657	$1,08,069	100
	DG	Battery	Converter		35	30	2.5	CC	$0.44	$4,51,337	$33,545	$17,682	0

TABLE 3. Optimization result with sensitivity variable.

Sensitivity		Combination of System				Architecture					Cost				
Disel Fuel Price ($/l)	Electrical Load kWh/day	PV	DG	Battery	Converter	PV (kW)	DG (kW)	Battery (Units)	Conv (kW)	Dispatch	COE ($)	NPC ($)	Operating Cost($)	intial capital($)	Ren Frac (%)
$1.00	220	PV	DG	Battery	Converter	69.1	35	38	31	LF	$0.111	1,15,173	$2,354	$84,736	96.7
$1.00	240	PV	DG	Battery	Converter	75.4	35	43	33.2	LF	$0.110	1,24,241	$2,481	$92,174	96.9
$1.05	220	PV	DG	Battery	Converter	69.1	35	40	31.2	LF	$0.111	1,15,720	$2,351	$85,324	96.9
$1.05	240	PV	DG	Battery	Converter	75.4	35	43	33.2	LF	$0.110	1,24,941	$2,559	$91,854	96.8

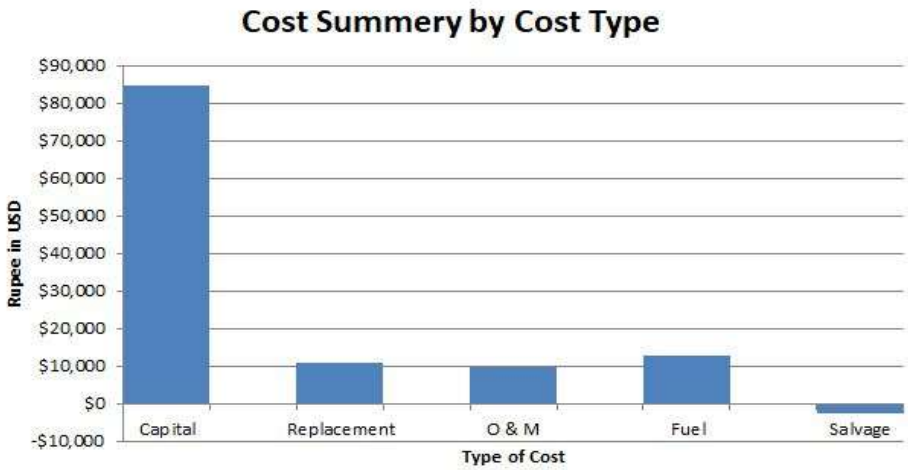

Fig. 3. Cost summery by cost type.

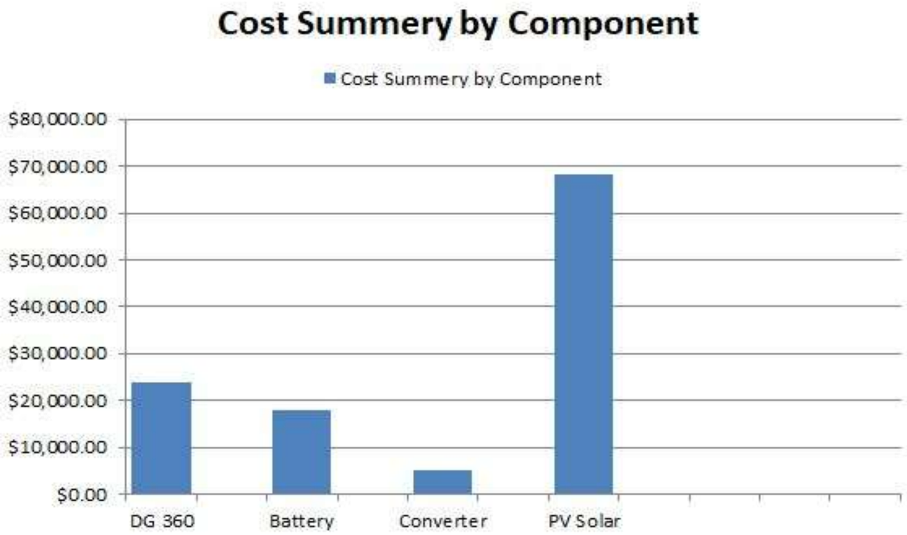

Fig. 4. Cost summary by component.

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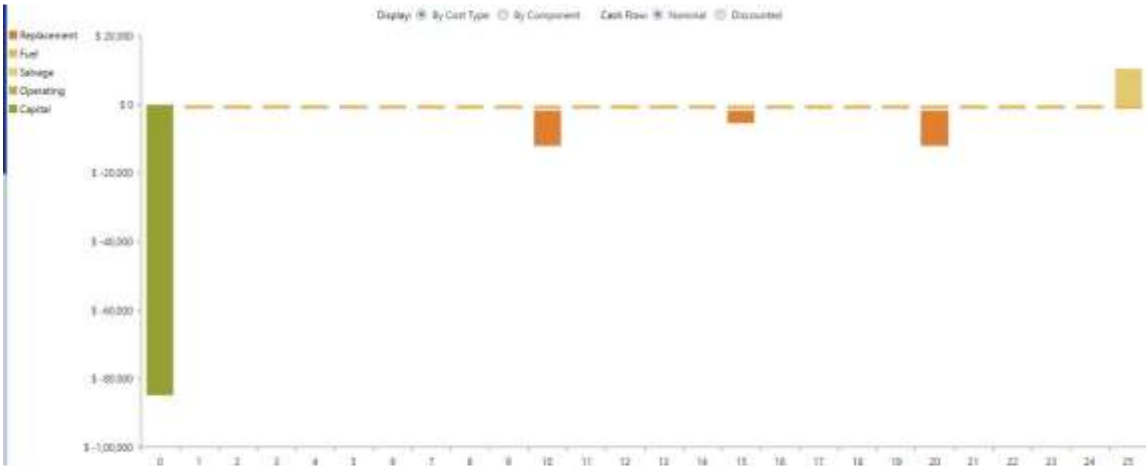

Fig. 5. Cash flow diagram.

As it can be seen the system comprising of the diesel generator, PV array with battery storage and power converter yields to the most economical cost with the minimum TNPC of Energy. The optimization result considers every sensitive variable gives different TNPC value of hybrid renewable energy system. It is worth mentioning that the sensitivity variables comprise of primary load and fuel price table 3 shows that the TNPC of PV, Generator and battery hybrid system become economically feasible when the primary load is varied from 219.97kWh/day to 240kWh /day. The system is also economical even if the diesel fuel price increase from the current 1$/L to 1.05$/L, which is actually expecting due to the variation of crude oil price. As it is observed from simulation PV/Gen/battery system is still optimum for the wide variation of load and diesel fuel price. Therefore, the optimum system for the case study village is PV/gen/battery system with the converter with minimum COE of $0.111/kWh.

TABLE 4. Emissions.

Quantity	Value	Units
Carbon Dioxide	2,552	kg/yr
Carbon Monoxide	16.1	kg/yr
Unburned Hydrocarbons	0.702	kg/yr
Particulate Matter	0.0975	kg/yr
Sulfur Dioxide	6.25	kg/yr
Nitrogen Oxides	15.1	kg/yr

Environmental Advantage

All energy sources have some impact on our environment but compare to conventional resources hybrid renewable energy sources have very less impact including air and water pollution, damage to public health, wildlife and habitat loss, water use, land use, and greenhouse gaseous emissions. Harnessing power from the wind is one of the cleanest and most sustainable ways to generate electricity as it produces no toxic pollution or global warming emissions. Similarly, the sun provides a tremendous resource for generating clean and sustainable electricity and it can be utilized by the better use of PV cell. The comparative data of greenhouse gaseous emission in both case i.e. conventional and hybrid renewable energy resources is given in table 4 as it can be seen there is a huge reduction of greenhouse gas which encourages such type of hybrid renewable energy resources system.

V. CONCLUSION

In this paper optimal configurations of hybrid renewable system for health clinic is assessed. The following conclusions were drawn based on this analysis;

- The PV/diesel/battery hybrid renewable system configuration is considered optimum for clinic according to NPC, COE and RF calculation.
- The diesel only system provides the highest COE ($0.435/kWh), emits high amounts of CO_2 per year; this is huge and will have adverse effect on the environment as well as the health of patients in the rural health facilities.
- The overall results indicated that not only does the hybrid system configurations perform better than diesel-only simulation with regards to the NPC, but also displayed better performance in the categories such as electrical, fuel consumption and CO_2 reduction.

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