Optimization of Renewable Energy Resources Based Microgrid System for Remote Area

Pratibha Shukla Tripathi[1], Ajay Tripathi[2*], Govind Sahu[3]

[1]*Research Scholar, Department of Electrical Engineering, Kalinga University, Naya Raipur-492101*

[2]**Professor, Department of Mechanical Engineering, Government Engineering College, Raipur-492015*

[3]*Assistant Professor, Department of Mechanical Engineering, Government Engineering College, Raipur-492015*

Abstract- India is an agricultural nation with an abundance of biomass resources and a bright future for solar energy. According to the study, the most practical off-grid hybrid solution includes PV and biomass systems. Solution in view of the monthly average solar radiation intensity, biomass resource availability of the design site bafra, Chhattisgarh, India. The most cost-effective simulation result has a COE of 8 Rs/kWh and an NPC of Rs 396773 with a renewable share of 100%. This proposed hybrid system is also environmentally friendly due to its low emissions of carbon dioxide 40.6 kg/yr and nitrogen 0.439 oxides kg/yr.

Keywords- Renewable Energy (RE); Wind Energy; Solar Energy; Net Present cost (NPC); cost of energy (COE).

1. INTRODUCTION

For a developing country like India, energy is a critical resource. There is still a power shortage in many rural parts of India, which is alarming. The world urgently requires alternative energy sources to meet the rising energy demand caused by the fast depletion of fossil fuels. For a multitude of reasons, including the mounting threat of global warming, we should minimize our reliance on fossil fuels (Ahammed, 2021). Future power grid growth will be highly reliant on renewable energy generation technology. Renewable energy techniques include the production of power from wind, solar, biomass, micro-hydro (MH), ocean wave, geothermal, and tide energy sources. The main benefits of energy systems include supply, security, reduced carbon emissions, improved electricity quality, dependability, and employment opportunities for the community. Two or more power sources must be combined in a hybrid configuration due to the irregular nature of renewable energy supply. Consumption of energy also plays a part in the region's growth. Solar energy is the greatest choice for effectively replacing traditional power sources and reliably meeting the nation's expanding load demand in certain parts of India. One of the most versatile approaches that India employs is hybrid system analysis i.e. numerous studies on renewable energy sources that have been conducted worldwide (Mathema, 2011). The usage of hybrid systems allows for the use of a variety of renewable energy configurations, such as wind-biomass-hydro-grid, solar-wind, PV system, solar-biomass-DG set, and so on. The hybrid renewable energy systems (HRES) paradigm is depicted schematically in Figure 1. The figure illustrates solar and wind energy supplying electricity to the end-user or the consumers. The output P_{pv} from the solar PV is fed into the DC-DC converter. This converter will regulate the DC voltages and then pass to the DC bus bar. The output Pwt from a wind turbine is given as an input to the AC-DC converter and then passes to the DC bus bar. A battery can also be used to store energy. Between the battery and the DC bus bar, a DC-DC converter is utilised. With the help of this DC-DC converter, the battery will charge when the power generation is in excess and it will discharge when the power generation is not able to meet the load demand. There is also an AC bus bar in the system from which the load will consume power P_{load}. The pathway between the DC bus bar and the AC bus bar consists of a DC-AC converter and a transformer. Renewable energy resources are abundant in nature, but their availability is dependent on weather conditions and location. A hybrid system that combines one or more renewable resources with a battery is more promising and has higher reliability than a conventional energy source (Rout and Sahu, 2018; Fulzele and Dutt, 2012; Pemndje et al., 2016; Peirow et al., 2022).

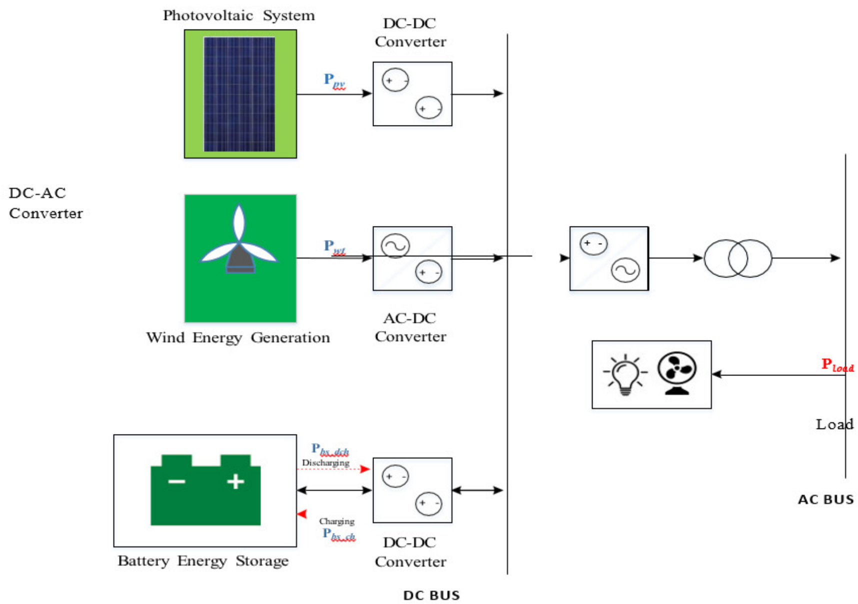

Figure 1. Solar-wind hybrid micro grid system

This hybrid power system is preferable in remote and isolated areas. Simultaneously, nonrenewable energy resource depletion is maintained under control. The output of photovoltaic (PV) panels and the electricity supplied by wind turbines frequently vary due to the inconsistencies and unpredictability of solar and wind energy. As a result, a massive number of energy storage systems are required for providing electricity to consumers in standalone mode and thus relying on the utility grid. This problem may be handled by integrating solar and wind characteristics, as well as considering the complementary qualities of solar and wind energy (Woyte et al. 2006). A well-designed wind, battery, and solar energy system can lower the total system cost and also improve the power supply reliability (Srivastava and Giri 2016). In a grid-connected hybrid system, the grid is retained as a backup power supply to satisfy the needed load demand (Yasin and Alsayed 2021; Khan et al. 2018).

The method and practice for providing electricity to isolated and rural places is known as rural electrification. There have been several researches on rural electrification. In most situations, connecting the main grid with rural isolated areas is both expensive and inefficient and it leads to the developing nations to find new ways to electrify their rural areas. As a result, those microgrids that use non-conventional energy resources will be receiving more attention. Microgrids are being considered as a potential option because of their capacity to work independently of the main grid, as well as in the event that the main grid is connected to the isolated community in the future, they can be built to interface with it. In order to solve the issue of electricity shortages, several initiatives are being introduced in developing and underdeveloped nations. These microgrids make use of traditional sources as well as renewable energy sources. Solar PV is used in the majority of cases, and it is set up in the areas where there is shortage of electricity and is located far from the main grid.

This research investigates an off-grid solar system with lead battery storage in the village of "Bafra" in the Baloda Bazar region of Chhattisgarh, India. This settlement may be found at 21.4763°N and 82.3872°E with the help of the Homer Pro software the solar, battery, converter design is the best among a variety of system configurations since it has the lowest energy cost (LCOE) and NPC.

1.1. Problem Statement

I. Easy access to power in remote areas where the grid cannot reach, affecting the area owing to a lack of resources.

II. To eliminate pollution, reduce the usage of fossil fuels and enhance the production of renewable energy.

III. The system we are developing should be capable of withstanding all forms of intricacy, such as (physical, economic, and environmental.

1.2. Analysis of Hybrid Renewable Energy System for Electrification of Remote Area

The Hybrid Renewable Energy Systems are in most cases, an integration of two or higher sources of many renewable energy sources, including solar-wind, solar-hydro, solar-diesel generator sets, etc. The necessity for HRES stems from the reality that each distinct renewable resource has drawbacks of its own, such as Solar panels can sometimes be costly to construct, leading to a longer time lag for electric bill savings to approximate initial investments. The production is completely dependent on the availability of a specific area to daylight, the most important benefit of HRES these days is that it allows us to make the optimum utilization of the renewable - energy generation technique performance parameters and achieve efficiencies that are higher than those obtained when a single source of energy is used for a particular location. Numerous components should be considered while dealing with hybrid renewable energy systems for the production of electrical energy. The most significant elements of these are their dependability and affordability; owing to climatic change, it is reasonable to evaluate various possibilities that hybrid generation utilities are generally more dependable and less expensive than systems that depend only one source of power.

1.2.1 Methodology

HOMER software was first developed by the National Renewable Energy Laboratory (NREL) in the United States of America (USA). It is commonly utilized to develop and analyze hybrid power systems. Demand load data, speed of wind and solar irradiation statistics, as well as elements descriptions and pricing, are presented as HOMER input data in this work. The optimization method is performed using HOMER Pro software, and Figure 2 provides a flowchart of the process.

Following a load study or load estimation, we will look into the potential availability of the resources.

In this work the Solar energy is the selected as primary resource for study. For instance, a diesel generator set and storage battery are used as a backup on overcast days when resources are not accessible. The most important inputs of the research are the value of solar radiation. And other inputs include the initial investment cost as well as the maintenance and replacement expenses for the batteries, generator set, and solar panels. The HOMER tool allows us to streamline the optimization process. The modeling technique can use data from several sources, such as generators and batteries, in addition to renewable energy sources including geothermal, wind, solar, and hydropower (Belu et al. 2014). Sensitivity analysis, simulation, and optimization are the three main analyses of the software.

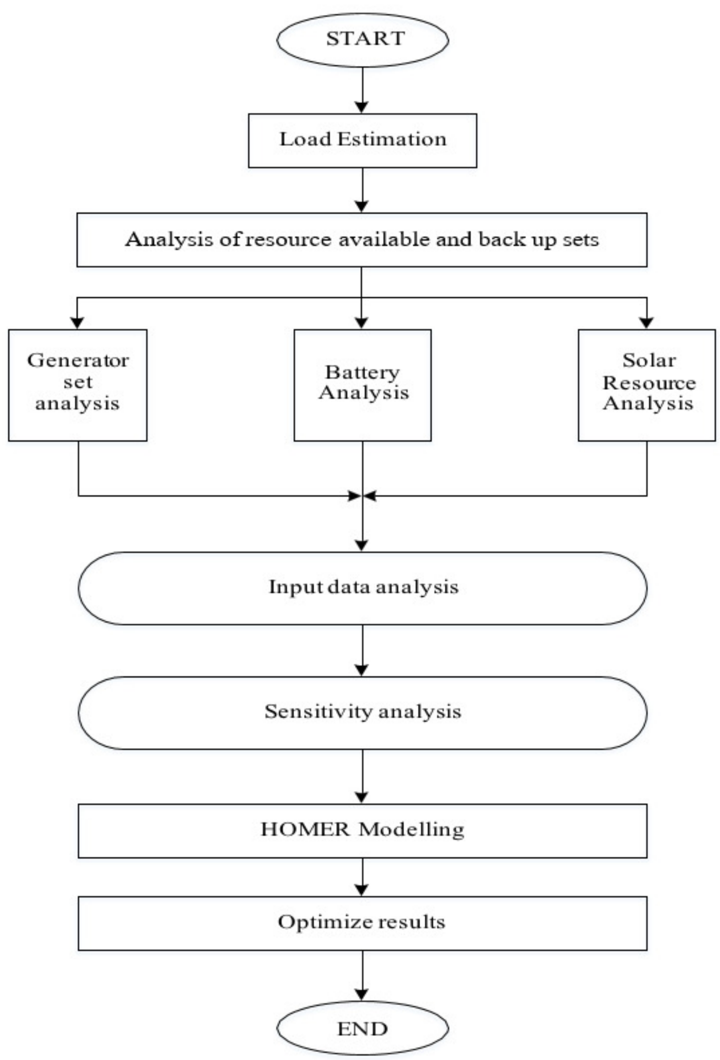

Figure 2. Flow chart of the optimization process

2. METHODS AND MATERIAL

2.1. Research Methodology

A range of economic evaluations or optimizations are used to create the optimal hybrid energy system design. The design and implementation of wind turbines and solar PV for providing electricity to remote areas are highlighted in this research. Special optimization techniques and tools such as BSA and HOMER are used for the optimization of hybrid renewable energy system and it determines the contribution and dependence of the renewable sources in the whole system in providing electricity to the remote areas. Due to its abundance, lack of pollution, and ability to replenish itself, renewable energy has gained popularity. However, the reliability of these sources is often challenged, which is why hybrid renewable energy systems are necessary. It is essential that such a system be optimized. HOMER Pro software is used for this purpose. In the proposed method, proper sizing and optimizing of all the component system are done. The contributions of the elements used in the system are also discussed. The net present cost is included in the optimization issue.

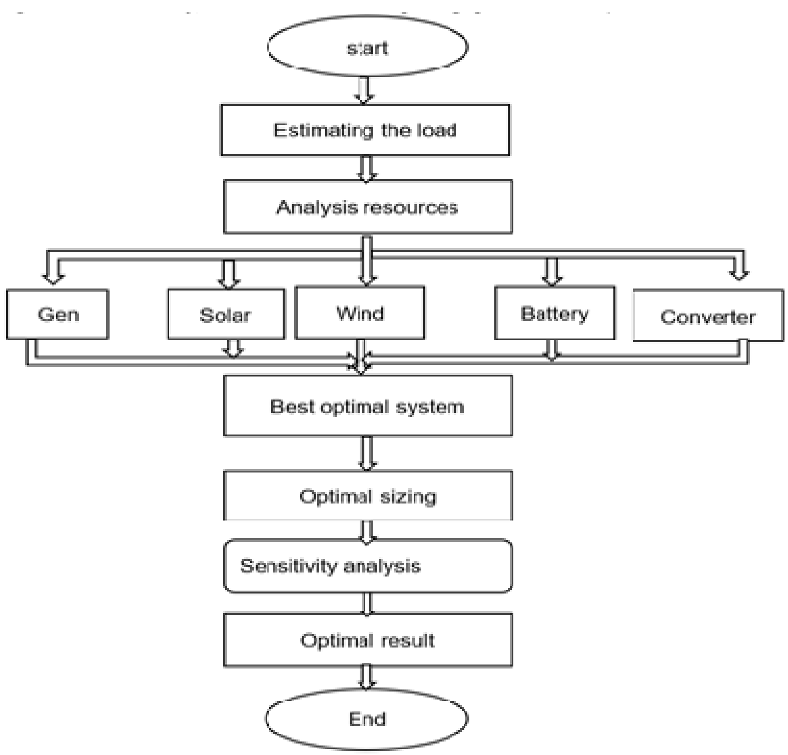

Figure 3. Research Methodology

In the case study, the results are obtained by modelling the entire system using HOMER and find the cost of producing power while fully using all available resources will be the major component that will be optimized (Swarnkar er al. 2016). The shape of energy is another important energy source employed in operations. The production of electricity and the subsequent transportation of energy have both created various obstacles. Transmission of electric power from a generation source to something like the end customers in a hilly terrain is an extremely difficult operation due to rising expenses. As a result, renewable energy appears to be a viable option that might provide a feasible way of transferring electricity to such hilly or isolated places. The flowchart of the process is shown in the Figure 3, and it begins with an estimate of the electric load, then analysis of resource after analyzing there are several combinations been made by homer software to find the best optimal system with the combination of various resource. The resources available in a certain application location are then scrutinized in search of suitable hybrid energy system components (Sandeep and Vakula, 2016).

2.2. Location of Study Area

The location chosen for the design of a micro grid system is bafra, which is situated baloda bazar district, Chhattisgarh India, with longitudes of 24°49'N and 93°55'E. There are in total 200 house in that village. Figure 4 shows the Geographical Location image of bafra.

Figure 4. Geographical Location

2.3. Load Estimation

In comparison to urban areas, demand for power is lower in a remote village. Electricity is required for domestic reasons (for devices such as Compact fluorescent lights (CFLs), ceiling or table fans, community loads such as street lights, agricultural loads such as water pumping loads, and communal loads such as a motor to head over water from a community well). Consequently, the load calculation was conducted with these considerations in mind. Figure 5 and Figure 6 shows the daily load profile and Seasonal load profile of the selected location.

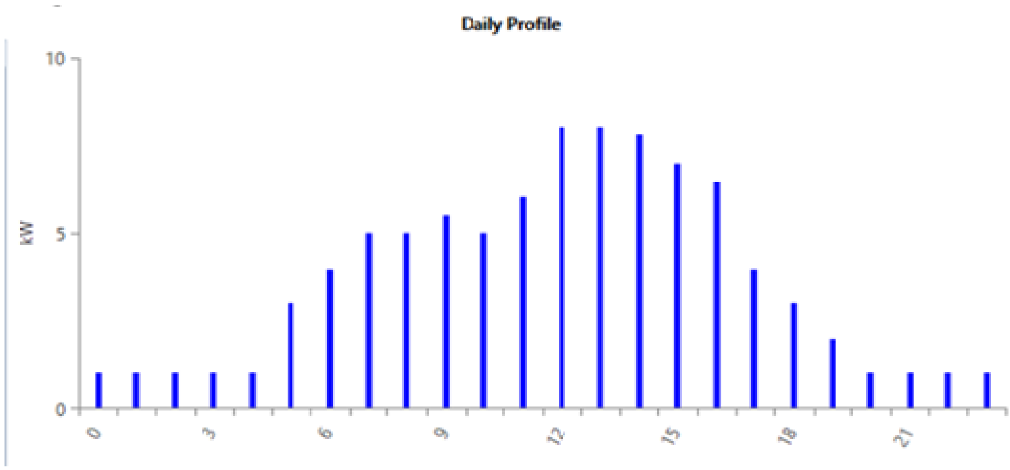

Figure 5. Daily load profile

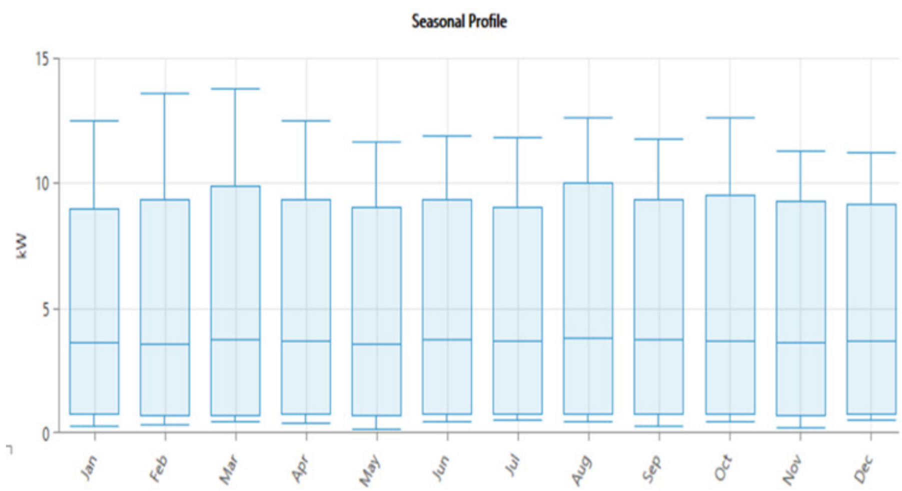

Figure 6. Seasonal load profile

2.4. Solar Radiation Data

The sun radiation measurements for bafra, were obtained from NASA. Figure 7 displays the clearness index value on the right vertical axis and the average daily solar radiation on the left vertical axis. 5.14 kwh/m2/day of solar radiation is the annual average (Sandeep and Vakula, 2016).

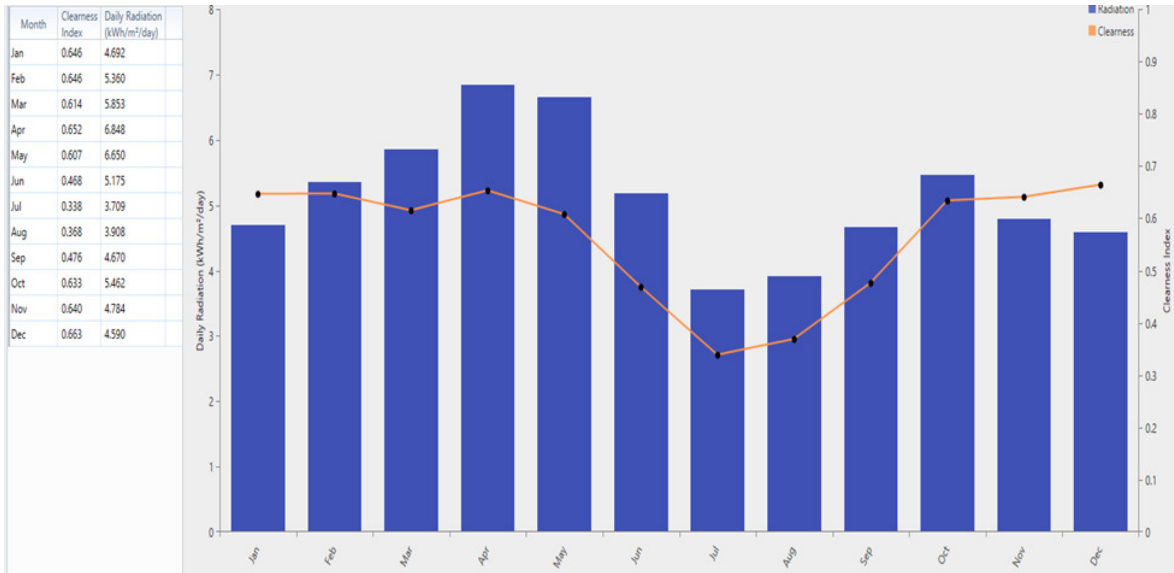

Figure 7. Solar Radiation Data

2.5. Wind Speed Data

NASA's surface metrology and solar energy databases are good sources for wind resource information. Based to the database, the average annual wind speed is 4.29 m/s. The monthly average wind speed varies from 2.86 m/s to 6.210 m/sec, with July having the highest and dec having the lowest values. The Figure 8 shows the selected site's average monthly profile of daily wind speed data (Joshi et al. 2016).

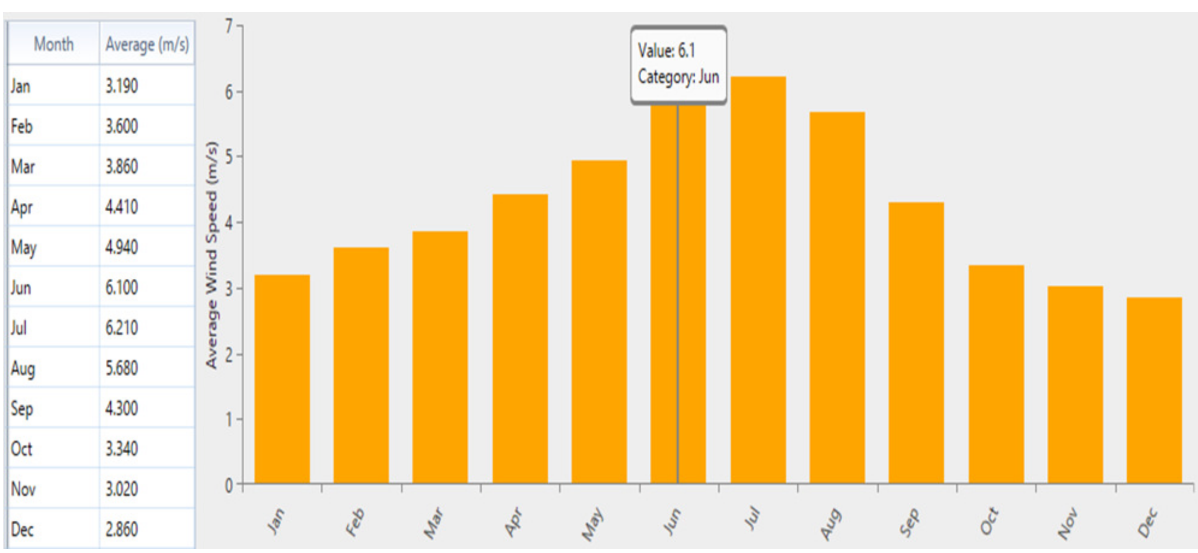

Figure 8. Wind Speed Data

2.6. HOMER Simulation Pro Model of Hybrid Energy System

The peak load demand of 1.75 kW, daily energy consumption of 11.27 kwh, and load factor of 0.32. The schematic diagram shows several parts attached to the AC and DC buses, with a converter in the center. It is necessary to know the specifics of each component and the availability of renewable energy over the course of a year in order to estimate the cost of a hybrid power system as tabulated in Table 1. Each component's specifics are broken down into capital cost, replacement cost, operation and maintenance cost, diesel cost as tabulated in the Table 2. The system is simulated by HOMER Pro 3.14.5 using various combinations of the available sources as shown in the Figure 9. The output consists of the component size, capital cost, net present cost, cost of energy per kWh, and other electrical parameters. The expected energy sources include solar panels, wind turbines, diesel generators, and battery storage. The system has off grid connection HOMER Pro 3.14.5.

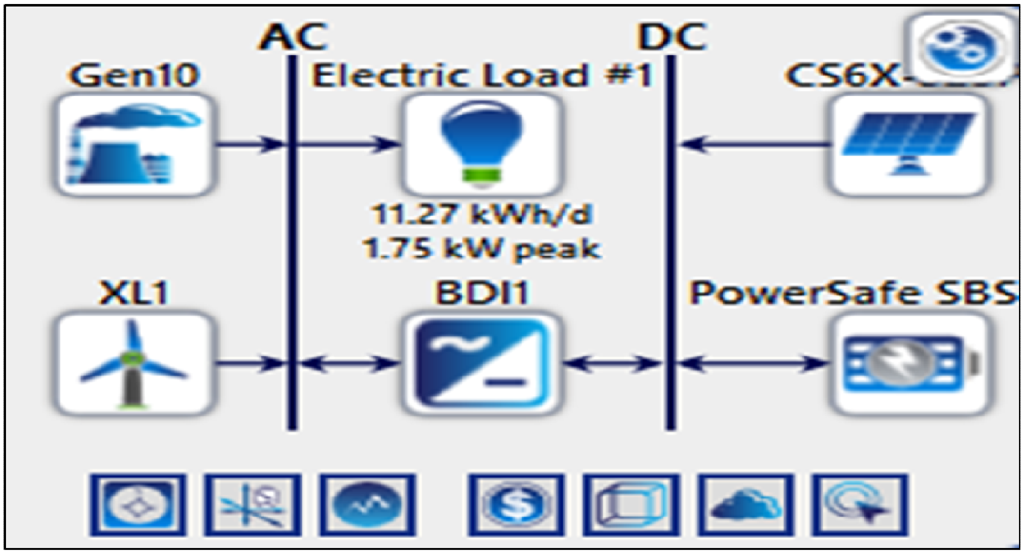

Figure 9. The hybrid renewable energy system's schematic diagram is displayed above and shows Simulation Model

Table 1. The estimated cost associated with a hybrid power system; according to standard supplier (UKC; GWE; BWP; PL; MP; Nijhawan et al. 2023).

SOLAR PHOTO VOLTIC (currency- Indian Rupee)	
Installation cost	12500
Replacement cost	13000
Operation and maintenance (O&M) cost	200
Life time	25
Wind turbine	
Installation cost	90000
Replacement cost	90000
Operation and maintenance (O&M) cost	900
Life time	20
DG Generator (currency- Indian Rupee)	**10kw**
Installation cost	5000

Replacement cost	5000
Operation and maintenance (O&M) cost	0.30
Life time	25
Battery	
Installation cost	86720
Replacement cost	86720
Operation and maintenance (O&M) cost	867
Life time	15yrs
Converter	
Installation cost	32000
Replacement cost	32120
Operation and maintenance (O&M) cost	200
Life time	20

Table 2. The cost associated with each components of hybrid system (including capital, replacement, operation and maintenance, diesel cost) (UKC; GWE; BWP; PL; MP; Nijhawan et al. 2023).

Component	**Capital** (Rs)	**Replacement** (Rs)	**O&M** (Rs)	**Fuel** (Rs)
Bergey BWC XC1	90000	0.0	10852.2	0.0
Canadian solar CS6X-32P	92710	0.0	13414	0.0
CAT BDI-SI-1Ph converter	57564.07	0.0	4338.24	0.0
Enersys SBS1800	86720	39445.27	10454.32	0.0
Generic 10kw genset	5000	0.0	25.32	10086.5
Other	0.0	0.0	4823.22	
Total system	331994	39445.2	43908.2	10086.5

2.7. Sensitivity analysis

Perform a sensitivity analysis by entering multiple values for a specific input variable for the following reasons: We can determine how significant a variable is and how its value affects the result by providing a range of values. Also, we can determine how "sensitive" the outputs are to changes in that variable. To make a single analysis applicable to several installations, one need undertakes a sensitivity analysis.

We had taken three different variables to determine the sensitivity of system:

1) Nominal discount rate

2) Fuel price

3) Expected inflation rate

Thus, by varying the values of variable we according to the table 3, had obtained a spider graph for our off-grid system in base case architecture to obtain best system which can withstand economic and physical change with due time as shown in the Figure 10.

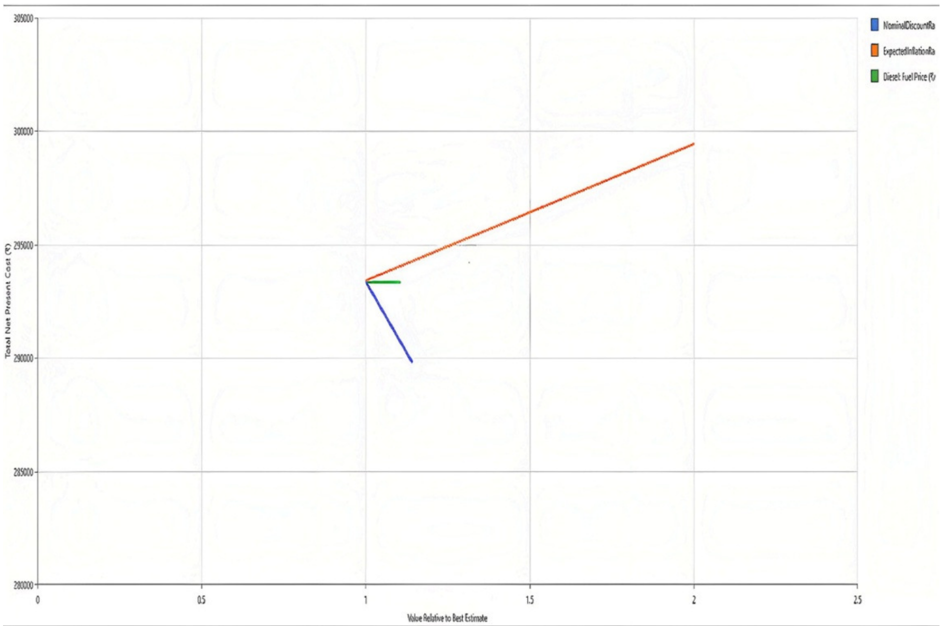

Figure 10. Spider Graph of off grid system

Table 3. Emissions by the hybrid systems with different combination of components

COMBINATION	EMISSION	NPC (Rs)	LCOE (Rs)	O&M (Rs)	RENEWABLE FRACTION (Rs)
SOLAR, BATTERY, CONVERTER	CO_2 - 0 kg/yr. CO - 0 kg/yr NO_2 - 0 kg/yr SO_2 - 0 kg/yr	452375	9.50	7082	100%
WIND, BATTERY, BIOGAS, GENERATOR, SOLAR, PV, CONVERTER	CO_2 - 40.6kg/yr CO - 0.307kg/yr NO_2 - 0.349kg/yr	396732	8	5369	99.6%

	SO_2 - 0.09 kg/yr				
SOLAR, WIND, BATTERY, CONVERTER	CO_2 - 0 kg/yr CO - 0 kg/yr NO_2 - 0 kg/yr SO_2 - 0 kg/yr	304514	6.40	4786	100%
SOLAR, BIOGAS GEN, BATTERY, CONVERTER	CO_2 - 81.2kg/yr CO - 0.614kg/yr NO_2 - 0.698kg/yr SO_2- 0.199kg/yr	415597	8.73	12636	98.4%
WIND, BIOGAS GEN, BATTERY, CONVERTER	CO_2 - 300 kg/yr CO - 2.27kg/yr NO_2- 2.58kg/yr SO_2- 0.73kg/yr	614851	12.91	16983	94.2%
WIND, BATTERY, CONVERTER	CO_2 - 0 kg/yr CO - 0 kg/yr NO_2- 0 kg/yr SO_2- 0 kg/yr	904771	19	9937	100%
BIOGASGEN, BATTERY, CONVERTER	CO_2 - 551 kg/yr CO - 41.7kg/yr NO_2- 47.4kg/yr SO_2- 13.5kg/yr	2.33M	49.61	180945	0%
WIND, BIOGAS GEN	CO_2 - 660 kg/yr CO - 49.9kg/yr NO_2 - 56.7kg/yr SO_2 - 16.2kg/yr	3.02M	63.37	186825	0%

3. RESULT & DISCUSSION

3.1. Summarized Result

All the combinations that are available for each setup and component are simulated by HOMER Pro 3.14.5 estimates the total net present cost of all feasible systems and lists them in ascending order of total net present cost in the optimization results. Thus, the hybrid optimized configuration is the system with the lowest overall net present value. The analysis of the results shows that the (PV, BIOGAS GENSET, CONVERTER-BATTERY, WIND TURBINE) system is the most optimal design. It requires a 2.41KW SOLAR PV, a 10 KW diesel generator,1 quantity of string of 24.8 KWh lead acid batteries, and a 1.80 KW converter.

3.2. Simulation Result

As a result of the simulation, all infeasible combinations are eliminated, and the feasible systems are ranked un order of increasing net present cost. This system's overall the functions of a PV array, DG set, battery bank, and converter are to produce electrical energy. The PV array covers around 52.20% of the cost, and the DG set covers about 8.0 %, wind energy 39.8%. Figure 11 shows the optimized result of simulation.

Architecture						Cost				System		Gen10						CS6X-325P		XL1		
CS6X-325P (kW)	XL1	Gen10 (kW)	PowerSafe SBS 1800 (#)	BDI1 (kW)	Dispatch	NPC (₹)	LCOE (₹/kWh)	Operating cost (₹/yr)	CAPEX (₹)	Ren Frac (%)	Total Fuel (L/yr)	Hours	Production (kWh)	Fuel (L)	O&M Cost (₹/yr)	Fuel Cost (₹/yr)	CAPEX	Energy Production (kWh/yr)	Capital Cost (₹)	Production (kWh/yr)	O&M Cost (₹)
3.89			1	1.24	CC	₹291,308	₹8.23	₹,818	₹245,282	100	0						118,794	3,070			
2.50	1		1	0.917	CC	₹356,686	₹7.37	₹,518	[illegible]	100	0						96,154	4,103	90,000	1,278	900
2.41	1	10.0	1	1.80	LF	₹396,738	₹8.00	₹,389	₹331,986	99.8	8.36	7.00	17.5	8.36	2.10	836	92,711	3,956	90,000	1,278	900
4.42		10.0	1	1.96	LF	₹407,138	₹8.21	₹,880	₹324,173	99.6	27.5	23.0	57.5	27.5	6.90	2,748	169,844	7,248			
	10		2	1.07	CC	₹1.28M	₹28.04	₹4,536	₹1.11M	100	[illegible]								900,000	12,788	9,000
	6	10.0	1	2.10	LF	₹1.30M	₹26.18	₹9,894	₹699,036	79.2	410	343	858	410	103	40,988			540,000	7,673	5,400
		10.0	2	4.52	CC	₹2.40M	₹48.44	₹67,121	₹187,096	0	1,580	608	4,530	1580	182	158,008					
20.7	10	10.0		1.65	CC	₹6.31M	₹127.31	₹378,888	₹1.36M	0	3,618	3,031	7,570	3618	908	361,846	707,776	34,045	900,000	12,788	9,000
	19	10.0			CC	₹8.16M	₹164.55	₹534,598	₹1.72M	0	5,146	4,306	10,765	5146	1,292	514,567			1,710,000	24,298	17,100
36.0		10.0		3.87	CC	₹9.08M	₹183.02	₹632,538	₹1.45M	0	6,204	5,196	12,980	6204	1,558	620,444	1,384,615	59,089			
		10.0			CC	₹12.7M	₹256.02	₹.05M	₹5,000	0	10,488	8,760	21,900	10,488	2,628	1,046,820					

Figure 11. Optimization result

3.3. Simulation and optimal Size Selection for Each Component

The highest output of solar PV is 2.31 kW when the sunlight is fully available, while the minimum output is 0 kW when the panel does not get enough sun insolation to generate power.3956 kWh of power was produced overall by solar PV system. The system's levelized cost alone is 8 Rs/kWh. Figures 12-15 and Table 4-7 shows the simulation results of PV, diesel generator, wind and storage respectively

Table 4. The simulation results of PV system

QUANTITY	**VALUE**	**UNIT**
Rated capacity	2.41	KW
Mean output	0.452	KW
Mean output	10.8	KWh/day
Capacity factor	18.7	%
Total production	3956	KWh/yrs.
Minimum output	0	KW
Maximum output	2.31	KW
PV penetration	96.2	%
Hour’s operation	4364	Hrs./yrs.
Levelized cost	2.08	Rs/kwh

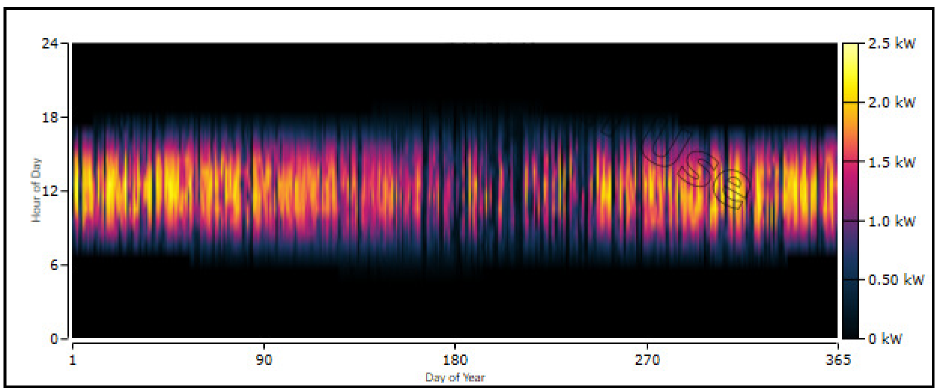

Figure 12. Simulation result PV

Table 5. The simulation results of diesel generator

QUANTITY	**VALUE**	**UNIT**
Hours of operation	7.00	Hrs./yr
Number of starts	7.00	Starts/yr
Operational life	2143	Yr
Capacity factor	0.02	%
Fixed generation cost	48.6	Rs/hr.
Marginal generation cost	28.6	Rs/KWh
Mean electrical output	2.50	KW

Minimum electrical output	2.50	KW
Maximum electrical output	2.50	KW

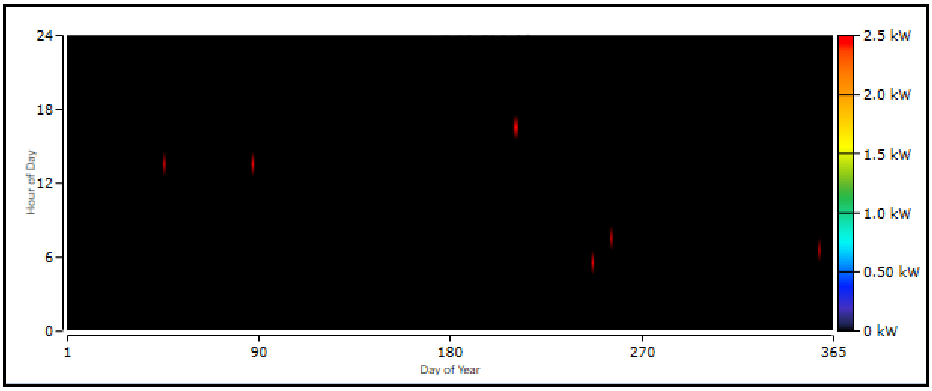

Figure 13. Simulation result of diesel generator

Table 6. The simulation results of wind

Quantity	**Value**	**Unit**
Total Rated capacity	1.00	KW
Mean output	0.146	KW
Capacity factor	14.6	%
Total production	1279	KWh/yrs.
Minimum output	0	KW
Maximum output	1.24	KW
Wind penetration	31.1	%
Hours of operation	5939	hrs./yrs.
Levelized cost	6.54	Rs/kwh

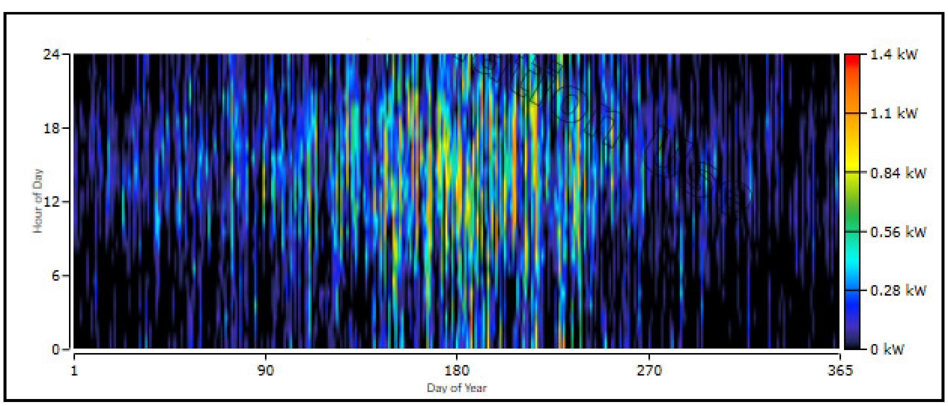

Figure 14. Simulation Result of Wind

Table 7. The simulation results of storage

QUANTITY	VALUE	UNIT
Nominal capacity	24.8	KWh
Usable nominal capacity	17.3	KWh
Autonomy	36.9	Hr
Storage wear out	3.33	Rs/KWh
Energy in	1097	KWh/yr
Energy out	1068	KWh/yr
Storage depletion	3.75	KWh/yr
Losses	33.0	KWh/yr
Annual throughout	1084	KWh/yr

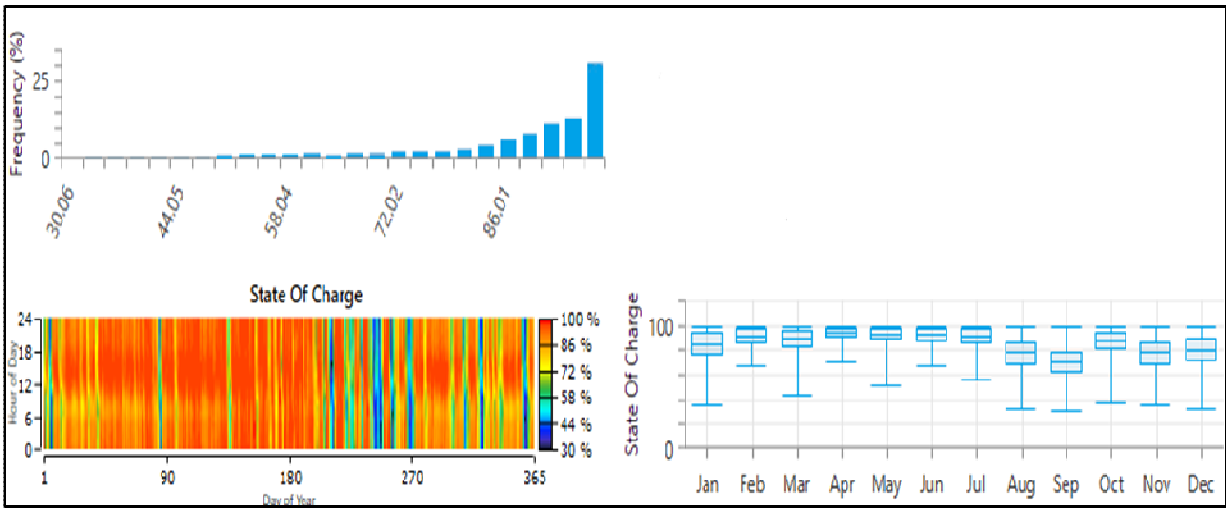

Figure 15. Simulation result of Storage

4. CONCLUSION

The purpose of this work is to design a hybrid system for an area without electricity at a level zed (least) cost of energy attained. An attempt is made to optimize the energy cost of a specific area in Chhattisgarh, India, considering that the area is completely isolated from the main grid. It is past time for us to look for other options and create a new system to meet the consumers' load demands. Because of its availability, pollution-free nature, and capacity to refill, renewable energy systems have become a high-priority option. However, the reliability of such sources has been questioned, resulting in the hybrid renewable energy system. The optimization of such a system is urgently required. The software HOMER Pro is used for this research. All of the component systems are properly sized and optimized using the proposed strategy. The contributions of the system's many components are also explored. The net present cost is included in the optimization issue. Although the designed system has a high installation cost, because of its low operating and maintenance costs, it is very profitable in the long run. It helps to raise the rural area's economic growth and standard of living. Therefore, taking this necessary action now will help prevent an energy crisis soon. Thus, Rural electrification can be challenging because rural areas may lack the necessary infrastructure to support electrical power, including power lines, transformers, and generators. In some cases, rural electrification may require the use of alternative energy sources, such as solar power or wind power. Rural electrification has been a priority for many countries around the world, particularly in developing countries where a large portion of the population lives in rural areas. Governments, non-profit organizations, and private companies have all been involved in rural electrification efforts, working to bring electricity to rural areas and improve the lives of the people who live there.

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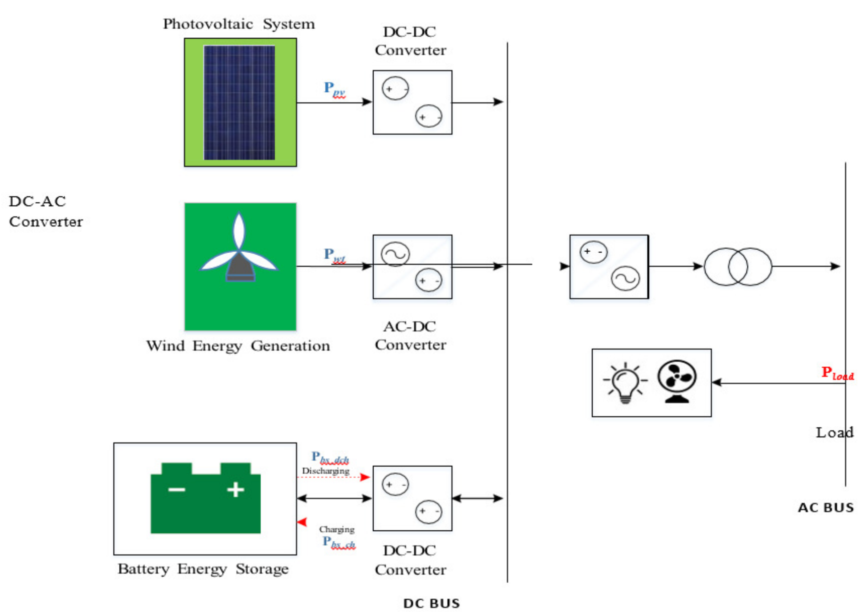

Figure 1. Solar-wind hybrid micro grid system

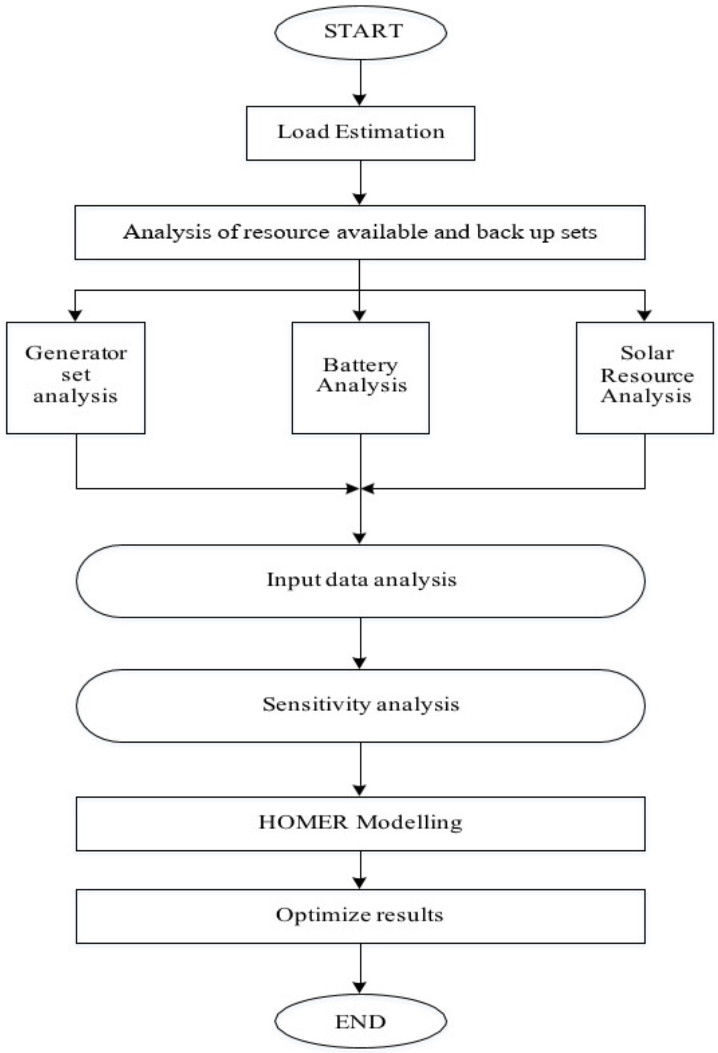

Figure 2. Flow chart of the optimization process

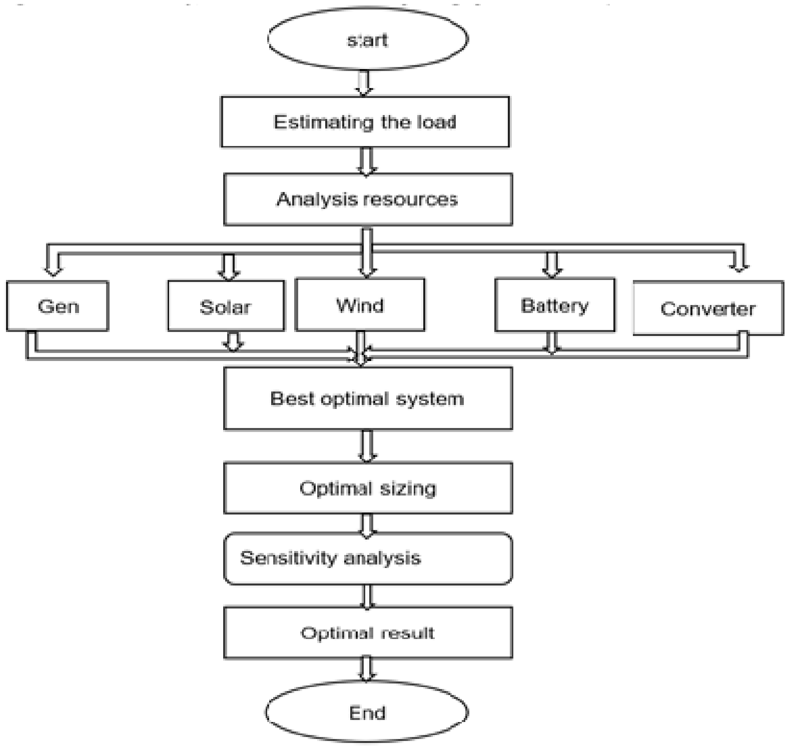

Figure 3. Research Methodology

Figure 4. Geographical Location

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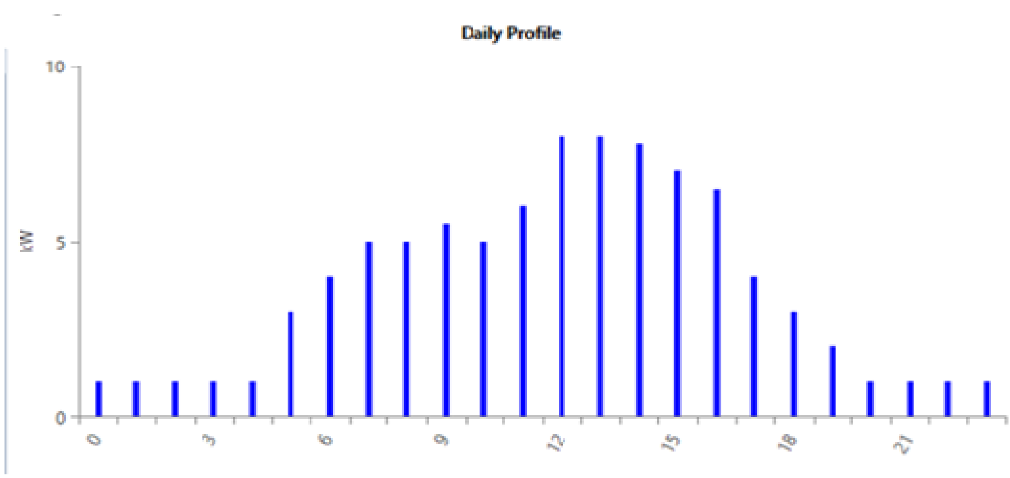

Figure 5. Daily load profile

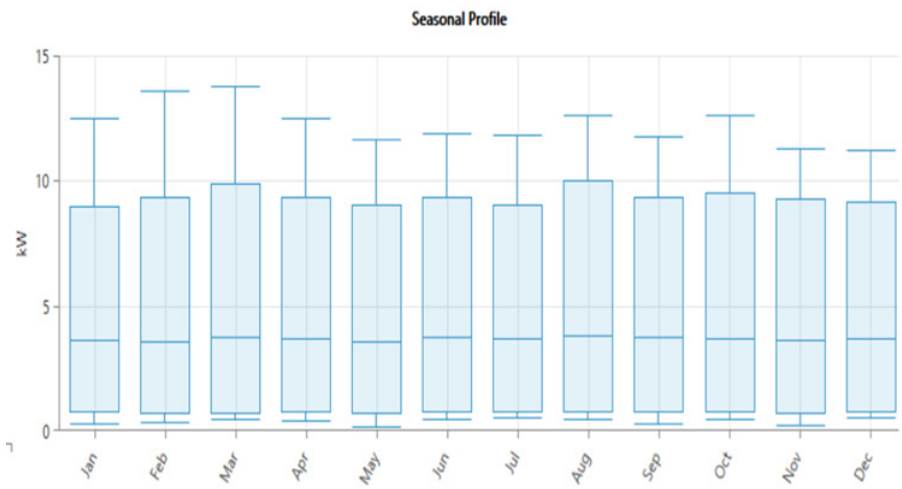

Figure 6. Seasonal load profile

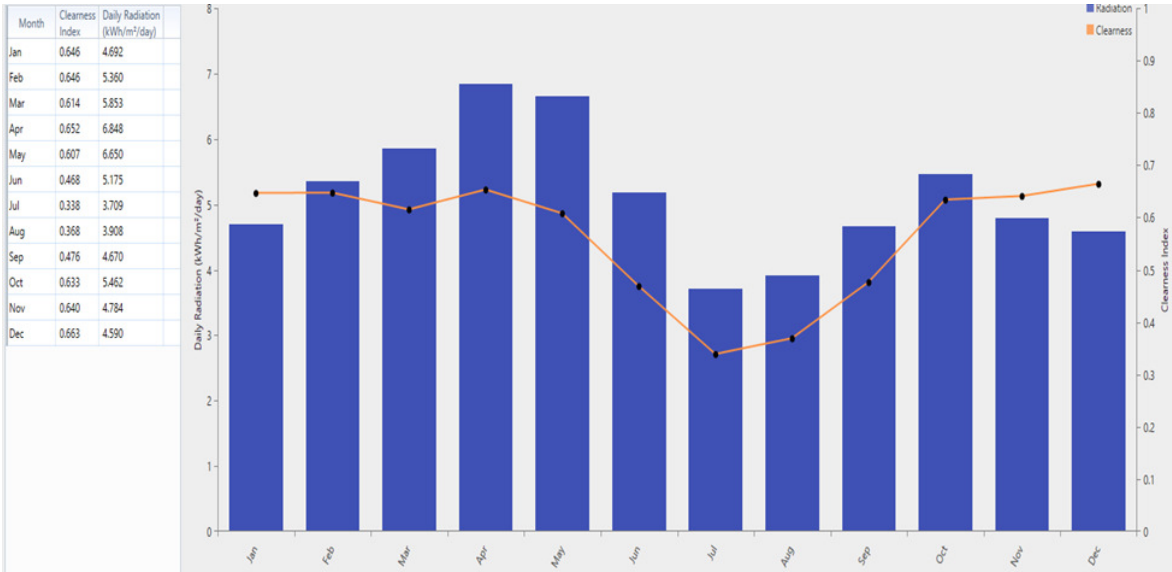

Figure 7. Solar Radiation Data

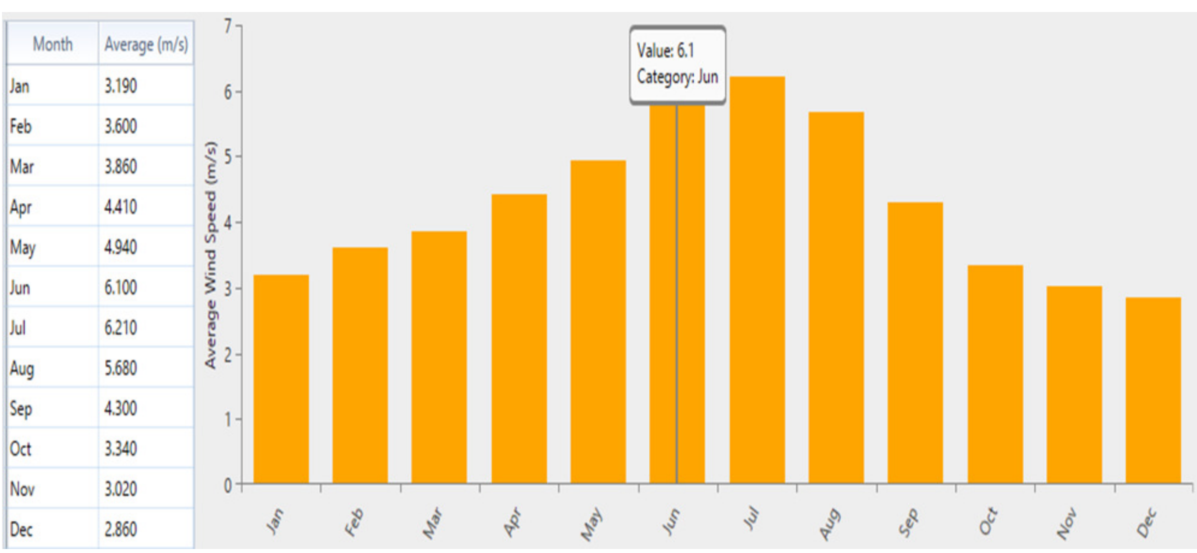

Figure 8. Wind Speed Data

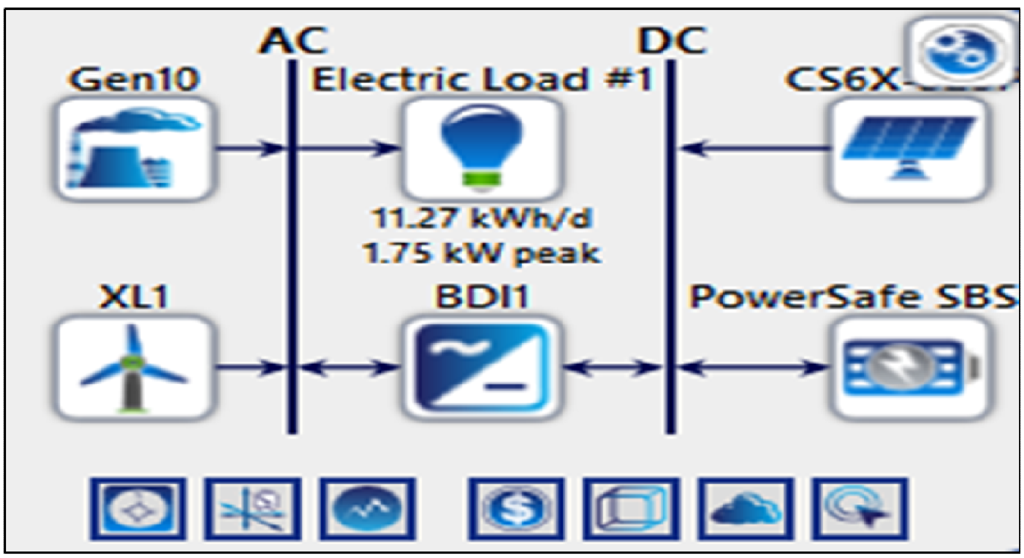

Figure 9. The hybrid renewable energy system's schematic diagram is displayed above and shows Simulation Model

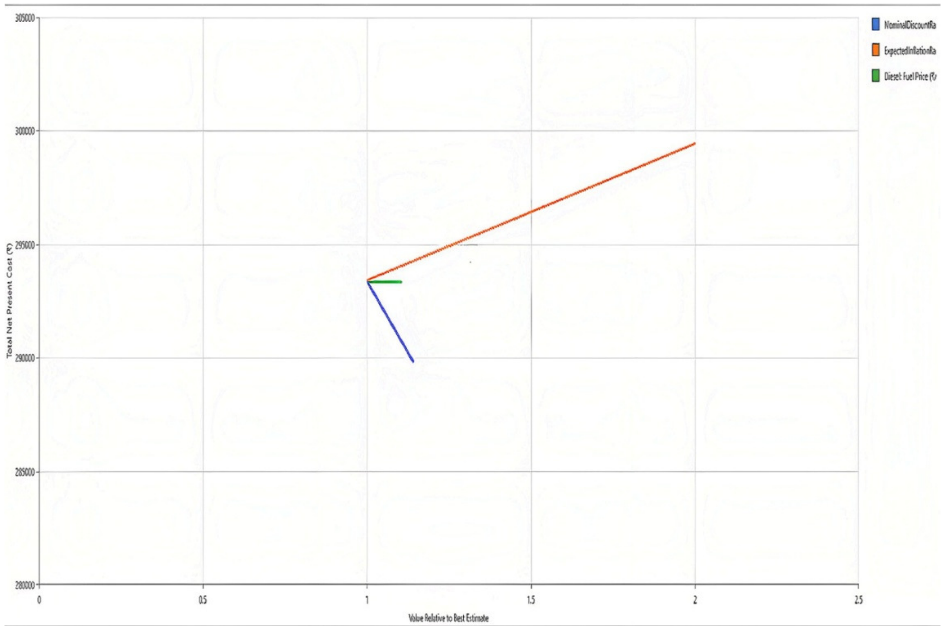

Figure 10. Spider Graph of off grid system

Architecture						Cost				System	
CS6X-325P (kW)	XL1	Gen10 (kW)	PowerSafe SBS 1800 (#)	BDI1 (kW)	Dispatch	NPC (₹)	LCOE (₹/kWh)	Operating cost (₹/yr)	CAPEX (₹)	Ren Frac (%)	Total Fuel (L/yr)
3.89			1	1.24	CC	₹291,308	₹6.23	₹,818	₹145,262	100	0
2.50	1		1	0.917	CC	₹356,686	₹7.37	₹,518	[illegible]	100	0
2.41	1	10.0	1	1.80	LF	₹396,738	₹8.00	₹,389	₹131,986	[illegible]	8.36
4.42		10.0	1	1.96	LF	₹407,138	₹8.21	₹,880	₹124,173	90.6	27.5
	10		2	1.07	CC	₹1.20M	₹24.04	₹-4,146	₹1.11M	100	0
	6	10.0	1	2.10	LF	₹1.30M	₹26.18	₹9,694	₹699,036	79.2	410
		10.0	2	4.52	CC	₹2.40M	₹48.44	₹167,121	₹187,096	0	1,580
30.7	10	10.0		1.65	CC	₹6.31M	₹127.31	₹370,888	₹1.36M	0	3,618
	19	10.0			CC	₹8.16M	₹164.55	₹534,539	₹1.72M	0	5,146
50.0		10.0		1.87	CC	₹9.08M	₹183.02	₹632,538	₹1.45M	0	6,204
		10.0			CC	₹12.7M	₹256.02	₹1.05M	₹5,000	0	10,488

Gen10					CS6X-325P		XL1		
Hours	Production (kWh)	Fuel (L)	O&M Cost (₹/yr)	Fuel Cost (₹/yr)	CAPEX	Energy Production (kWh/yr)	Capital Cost (₹)	Production (kWh/yr)	O&M Cost (₹)
					118,794	5,070			
					96,154	4,103	90,000	1,278	900
7.00	17.5	8.36	2.10	836	92,711	3,956	90,000	1,278	900
23.0	57.5	27.5	4.60	2,748	160,844	7,248			
							900,000	12,788	9,000
343	858	410	103	40,988			540,000	7,673	5,400
608	4,530	1580	182	158,008					
3,033	7,570	3618	908	361,846	797,776	34,045	900,000	12,788	9,000
4,306	10,765	5146	1,292	514,567			1,710,000	24,288	17,100
5,196	12,980	6204	1,558	620,444	1,384,615	59,089			
8,760	21,900	10,488	2,628	1,048,820					

Figure 11. Optimization result

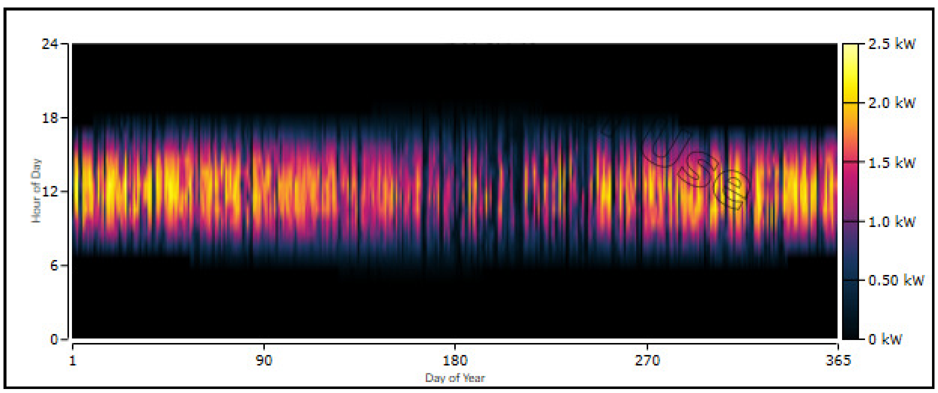

Figure 12. Simulation result PV

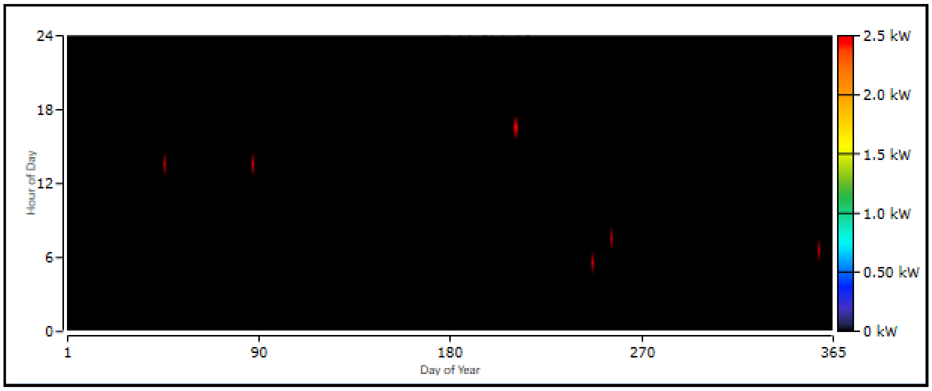

Figure 13. Simulation result of diesel generator

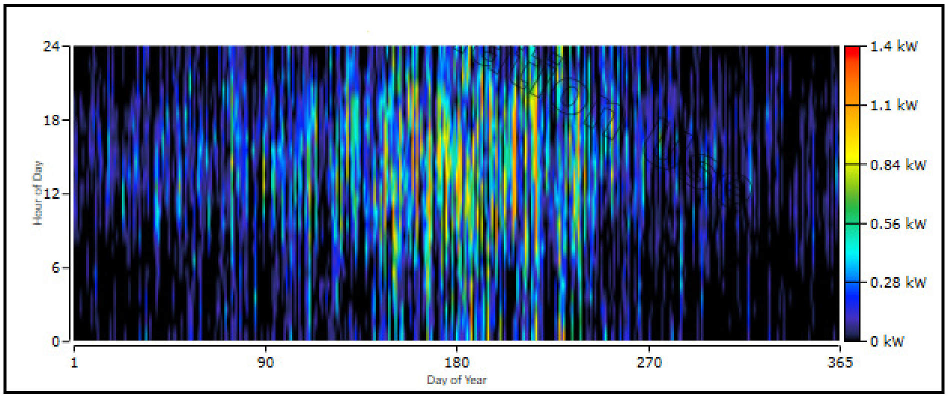

Figure 14. Simulation Result of Wind

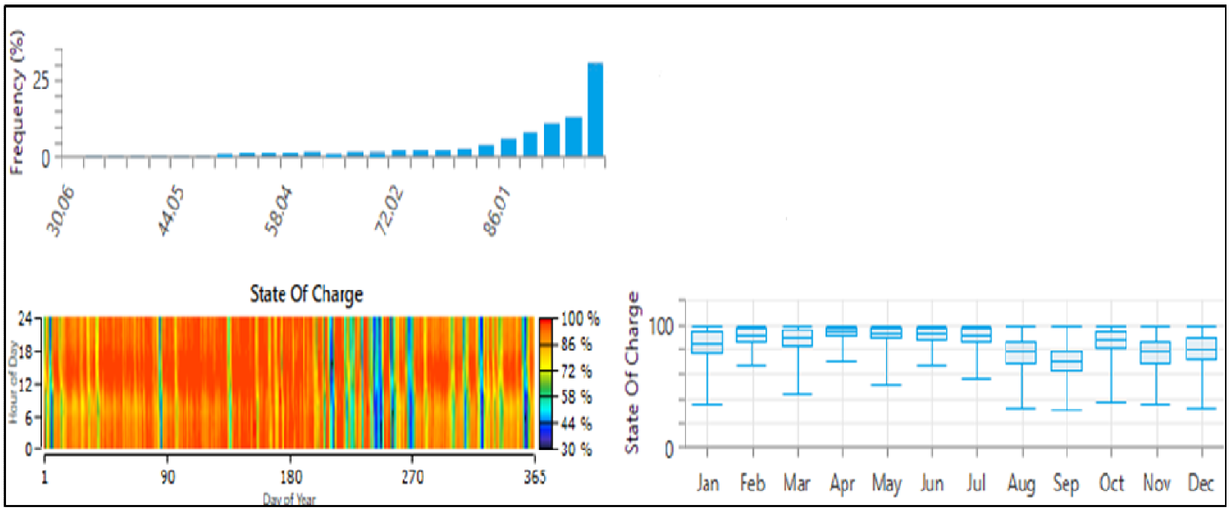

Figure 15. Simulation result of Storage

Table 1. The estimated cost associated with a hybrid power system; according to standard supplier (UKC; GWE; BWP; PL; MP; Nijhawan et al. 2023).

SOLAR PHOTO VOLTIC (currency- Indian Rupee)	
Installation cost	12500
Replacement cost	13000
Operation and maintenance (O&M) cost	200
Life time	25
Wind turbine	
Installation cost	90000
Replacement cost	90000
Operation and maintenance (O&M) cost	900
Life time	20
DG Generator (currency- Indian Rupee) 10kw	
Installation cost	5000
Replacement cost	5000
Operation and maintenance (O&M) cost	0.30
Life time	25
Battery	
Installation cost	86720
Replacement cost	86720
Operation and maintenance (O&M) cost	867
Life time	15yrs
Converter	
Installation cost	32000
Replacement cost	32120
Operation and maintenance (O&M) cost	200
Life time	20

Table 2. The cost associated with each components of hybrid system (including capital, replacement, operation and maintenance, diesel cost) (UKC; GWE; BWP; PL; MP; Nijhawan et al. 2023).

Component	**Capital** (Rs)	**Replacement** (Rs)	**O&M** (Rs)	**Fuel** (Rs)
Bergey BWC XC1	90000	0.0	10852.2	0.0
Canadian solar CS6X-32P	92710	0.0	13414	0.0
CAT BDI-SI-1Ph converter	57564.07	0.0	4338.24	0.0
Enersys SBS1800	86720	39445.27	10454.32	0.0
Generic 10kw genset	5000	0.0	25.32	10086.5
Other	0.0	0.0	4823.22	
Total system	331994	39445.2	43908.2	10086.5

Table 3. Emissions by the hybrid systems with different combination of components

COMBINATION	**EMISSION**	**NPC (Rs)**	**LCOE (Rs)**	**O&M (Rs)**	**RENEWABLE FRACTION (Rs)**
SOLAR, BATTERY, CONVERTER	CO_2 - 0 kg/yr. CO - 0 kg/yr NO_2 - 0 kg/yr SO_2 - 0 kg/yr	452375	9.50	7082	100%
WIND, BATTERY, BIOGAS, GENERATOR, SOLAR, PV, CONVERTER	CO_2 - 40.6kg/yr CO - 0.307kg/yr NO_2 - 0.349kg/yr SO_2 - 0.09 kg/yr	396732	8	5369	99.6%
SOLAR, WIND, BATTERY, CONVERTER	CO_2 - 0 kg/yr CO - 0 kg/yr NO_2 - 0 kg/yr SO_2 - 0 kg/yr	304514	6.40	4786	100%

SOLAR, BIOGAS GEN, BATTERY, CONVERTER	CO_2 - 81.2kg/yr CO - 0.614kg/yr NO_2 - 0.698kg/yr SO_2- 0.199kg/yr	415597	8.73	12636	98.4%
WIND, BIOGAS GEN, BATTERY, CONVERTER	CO_2 - 300 kg/yr CO - 2.27kg/yr NO_2- 2.58kg/yr SO_2- 0.73kg/yr	614851	12.91	16983	94.2%
WIND, BATTERY, CONVERTER	CO_2 - 0 kg/yr CO - 0 kg/yr NO_2- 0 kg/yr SO_2- 0 kg/yr	904771	19	9937	100%
BIOGASGEN, BATTERY, CONVERTER	CO_2 - 551 kg/yr CO - 41.7kg/yr NO_2- 47.4kg/yr SO_2- 13.5kg/yr	2.33M	49.61	180945	0%
WIND, BIOGAS GEN	CO_2 - 660 kg/yr CO - 49.9kg/yr NO_2 - 56.7kg/yr SO_2 - 16.2kg/yr	3.02M	63.37	186825	0%

Table 4. The simulation results of PV system

QUANTITY	VALUE	UNIT
Rated capacity	2.41	KW
Mean output	0.452	KW
Mean output	10.8	KWh/day
Capacity factor	18.7	%
Total production	3956	KWh/yrs.
Minimum output	0	KW
Maximum output	2.31	KW
PV penetration	96.2	%
Hour's operation	4364	Hrs./yrs.
Levelized cost	2.08	Rs/kwh

Table 5. The simulation results of diesel generator

QUANTITY	VALUE	UNIT
Hours of operation	7.00	Hrs./yr
Number of starts	7.00	Starts/yr
Operational life	2143	Yr
Capacity factor	0.02	%
Fixed generation cost	48.6	Rs/hr.
Marginal generation cost	28.6	Rs/KWh
Mean electrical output	2.50	KW
Minimum electrical output	2.50	KW
Maximum electrical output	2.50	KW

Table 6. The simulation results of wind

Quantity	Value	Unit
Total Rated capacity	1.00	KW
Mean output	0.146	KW
Capacity factor	14.6	%
Total production	1279	KWh/yrs.
Minimum output	0	KW
Maximum output	1.24	KW
Wind penetration	31.1	%
Hours of operation	5939	hrs./yrs.
Levelized cost	6.54	Rs/kwh

Table 7. The simulation results of storage

QUANTITY	VALUE	UNIT
Nominal capacity	24.8	KWh
Usable nominal capacity	17.3	KWh
Autonomy	36.9	Hr
Storage wear out	3.33	Rs/KWh
Energy in	1097	KWh/yr
Energy out	1068	KWh/yr
Storage depletion	3.75	KWh/yr
Losses	33.0	KWh/yr
Annual throughout	1084	KWh/yr