Study of Wind biomass hybrid model for rural electrification

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Abstract:

Rural electrification in remote areas, such as Leh Ladakh, presents a unique set of challenges due to harsh terrain, extreme weather conditions, and limited access to conventional energy sources. This abstract explores the implementation of an innovative, sustainable energy solution for Leh Ladakh through the integration of a Wind-Biomass-integrated system with Battery as secondary source of energy. The proposed system aims to address the energy needs of off-grid communities in Leh Ladakh, where the harsh climate and limited conventional energy infrastructure present significant challenges. The integration of wind turbines harnesses the region's abundant wind resources, while biomass generators provide a reliable energy source, particularly during low wind periods. The inclusion of battery storage enhances system resilience by mitigating intermittency and ensuring a continuous power supply. HOMER software is employed to conduct a comprehensive techno-economic analysis, optimizing the sizing and configuration of each component to maximize system reliability and minimize the levelized cost of electricity (LCOE). The results reveal an optimized hybrid energy system that not only meets the energy demands of the target communities but also demonstrates economic viability.

INTRODUCTION

Energy demand rises in tandem with monetary growth since it is proportional to economic growth. Regardless matter how many solutions are proposed for increasing the electricity limit, many people continue to live in non-electrified areas of non-industrial nations. Presenting nonrenewable energy resources would undoubtedly not meet energy demand since they are a limited [1]. Power has evolved into an incredible engine of social and financial development for each nation, and the total waste level of oil derivatives is rapidly increasing over the world. Regardless, with the world's rapid industrialization, a major energy crisis is looming in the near future. During the Financial Crisis, the price of oil in the world fell from around 147 dollars to nearly sixty dollars, a drop of almost ninety dollars from the peak [2]. The World Energy Forum predicts that fossil-based oil, coal, and gasoline reserves will be exhausted over the next ten years. Petroleum derivatives account for more than 79% of all energy consumed on the planet, with 57.7% of that total used in the vehicle industry and decreasing rapidly [3].

Several billion people in non-industrialized countries are not supplied with electricity since the bulk of them live in rural areas. Many of their energy wants are currently met by non-electric and conventional sources, for example, man and creature muscular energy, kindling, creature and lamp petroleum trash. Concerns of ecological annihilation caused by widespread use of fossil fuels, as seen in the global temperature increase phenomenon, have also piqued people's curiosity. To address these issues, wind power has been accepted as a good alternative for several other Energy forms due to its efficiency, and it is expected to contribute to the global status of the climate as a result of its cleanliness [4]. The depletion of common assets, as well as the increased demand for common power, have forced organizers and strategy developers to seek other alternatives. Renewable energy is energy derived from regenerative assets that do not deplete with time [3]. Recent original study in renewable energy sources has discovered significant promise, as a kind of helpful commitment to traditional force age frameworks [5]. Alternative energy sources, particularly green energy, are becoming increasingly appealing as a result of limited petroleum derivative stores and the negative effects connected with the use of oil products [6].

Biomass is defined as bio material derived from water-based waste, forest, or vegetation, as a result of crop development, agro, or food-processing waste. In India, various biomass assets are available in a number of frameworks. They can be classified according to their natural habitat as grasses, woody plants, organic products, vegetables, fertilizers, and amphibian plants. Green development, as well as Jatropha, are being employed in the production of bio diesel. Center obvious wellsprings of biomass energy might be allotted development of agricultural yield, energy administration, and mechanical and civic waste [7]. In India, there are several types of biomass waste available. These wastes might be converted into large amounts of energy known as bio energizes via a bio synthetic process known as thermal material transformation [8].

Biomass power is the principal renewable energy source that emits co2 (CO_2). The manner in which it is anything but an outstanding worry when there should be an incidence of reasonable employing. The biomass development cycle, as well as the power age cycle; the supplied CO_2 in ignitions devices are currently being employed in the biomass development cycle [9]. On the other hand, the GHG emissions from biomass energy are far lower than those from nonrenewable sources of energy [10].

There are numerous regions in India where the power provided by the grid is of poor quality and dependability is extremely low. This grid failure is caused by a variety of factors, the most important of which is a topographical feature. In the study, such a place is studied where grid electricity is unpredictable and unstable. The planned project received moderate wind speed throughout the year due to its geographical location. Wind power, on the other hand, is intermittent rather than continuous. To overcome this difficulty, certain storage devices must be preserved, with batteries being the most commonly used. The planned site also has a significant amount of biomass. They are made up of food waste, livestock waste, agricultural waste like stubble in the paddy field, and other bio material present locally. The biomass generator can provide a fixed quantity of electricity and, because it is not affected by weather, it will undoubtedly supplement wind energy to produce an acceptable amount of power to fulfill the community load.

The concept made use of a windmill and a biomass generator. Because wind turbines are inherently intermittent, a suitable amount of battery bank is installed to counteract this impact. The biomass and windmills provide electricity, and the surplus and deficit energy may be met by using a battery bank. To save money, the whole operation of a biomass generator may be scheduled. Thus the present work aims to introduce the integrated wind-biomass system and examines the feasibility of the system and optimize the system to provide cost effective and continuous power supply. The study is conceived in standalone mode in Leh ladakh region.

LITERATURE REVIEW

Kaushik et al. (2023), presented that India is blessed with many renewable energy sources such as solar and wind energy. Analyzing the capabilities of wind power sources is required for changing the country's power situation in order to construct wind turbine installations. Wind power cannot be depleted; it can only be replenished by nature. The effects of the coronavirus on wind energy are examined in this study, as are the various obstacles encountered by different states, as well as the many potential for the country [11]. Verma et al. (2022), discussed that wind energy is an alternative energy source derived from nonrenewable energy resources. The turbine is used to harness wind power. Different materials and metals are required for different components of a wind turbine. The results assessed the material and rare earth element requirements, as well as the future pricing for 100% wind energy generation in india [12]. R. Sitharthan and colleagues (2018) examinations the growing awareness of environmental change has compelled several countries to use renewable energy resources (RER) for electricity generation. Among the numerous RER, wind power age framework plays an important role, meeting around 28% of community energy need. This study focuses on a few significant potential outcomes in India for research on wind power function in the power era[13]. P K Chaurasiya et.al (2019) shows that India is actually honored with monstrous eco-friendly energy assets in general and wind energy assets specifically. To assess the ability of wind energy assets in changing the power circumstance in the nation is actually essential for enhancement of wind generator establishments in not so distant future. This particular paper examines the problems as well as openings of the improvement of wind electricity in the nation and moreover different ways to cope with increment and lengthen the use of wind assets [14]. S. Sharma et al. (2019), opined that using the strength of the wind to do beneficial things like pounding grains, siphoning water, and navigating boats has been around for what appears to be forever. Wind power is now being used to generate electricity in existing events. The findings of this research emphasize the effort led by the Indian government (central and state) in the wind energy region, demonstrating decreasing renewable energy expenditures, worked on monetary motivating factors, openings in seaward wind energy, and consistent sector expansion [15]. Narnaware et al. (2022), presented that biomass gasification is a viable renewable energy technology with enormous potential to reduce dependency on fossil fuels while simultaneously addressing environmental issues in long-term planning and meeting sustainable development goals. India has implemented excellent renewable energy policies, including biomass and bioenergy. The study provides an overview of gasification technologies and their many application pathways, as well as their techno-economic feasibility, role in climate mitigation, and policies, with an emphasis on biomass gasification in the context of the Indian situation [16]. Hung (2022), this study examines the time-frequency relationships between economic growth (GDP) and biomass energy consumption (BIO) in the United States, the United Kingdom, and the BRICS nations from 1990 to 2020 [17]. Kumar et al. (2015) audit the biomass energy asset, potential, energy shift, and development program implemented by the Government of India. Every year, India has an abundance of rural and woodland region, containing around 500 million metric tons of biomass accessible. In India, the total biomass power age limit is 17,500 MW. This research also looks at the many types of biomass in India. Furthermore, the research reveals that India has great potential for bio bulk feed inventories from various sources [18]. Vijay et al. (2022), stated that clean energy transition based on biomass resources has been identified as a significant climate change mitigation option. Because the localized nature of biomass is important, bioenergy usage should follow decentralized planning. . The report also covers several drivers and hurdles in establishing decentralized bioenergy facilities, such as logistical, institutional, financial, and technological. The current study's findings are intended to help renewable energy planners in India [19]. Tajeddinn et al. (2019) investigated that while Renewable Energy Sources (RES) have received a lot of attention in recent years, there are still concerns about competence and reliability. In this research, hybridization with biomass electricity improves the reliability and efficiency of a wind mill. The findings highlight the conclusion that biomass assets are a profitable way to compensate for wind energy deficits [20]. Tiwari et al. (2019), observed that the increasing speed of metropolitan lifestyle is causing both waste and major energy issues. This evaluation gives a possible assessment of a neighborhood location renewable power system(HRES) utilizing biomass to meet nearby power requirements while reducing family solid waste volume [21].

WIND PERFORMANCE ASSESSMENT

Prior to the display of wind energy in the lattice, administrators were keen on comprehending the nuances of the era that would help them during the time spent units' duty as well as the development price of the device in addition to turning holds. In many countries, the growing share of renewable energy in the energy mix, particularly wind turbines, has prompted administrators to reconsider supply the board in order to maintain network adaptability and add proficiency to integrate wind turbine force supply alongside other intermittent sources of energy [22]. Because of increased wind turbine coordination, the prediction assumes a significant role in lowering development costs, since the lack of expectation necessitates the existence of massive amounts of changing holds. Furthermore, erratic inclines have the potential to demolish the matrix's consistent quality. Finally, with wind turbines as a source of energy, anticipating is now advantageous for executive networking [23]. Regardless, there is no optimal procedure for the hope of wind energy, since it is one of the most changing meteorological difficulties to be pushed. Every strategy has its own set of problems and benefits, which may be appropriate in a few particular circumstances but erroneous in others [24].

BIOMASS ENERGY ASSESSMENT

Biomass is a carbonaceous infinite supply derived from the activities of biotic living organisms (plants, green growth, and animals). Biomass includes trees, agricultural and forest deposits, human or animal waste, energy crops, a natural component of municipal solid waste (MSW), food processing wastes, sewage etc [25-27]. With the continuous rise and changes in petroleum product costs, as well as growing environmental concerns about the emissions produced by petroleum product consumption, biomass could be a promising eco-friendly energy source to meet a variety of electrical power demands as a substitute for oil products. Biomass is the fourth largest source of energy on the planet, accounting for around 35% of energy consumption in non-industrialized nations and 3% in industrialized nations [28]. Furthermore, it addresses a greater adaptability gas supply with strong start soundness due to the large unanticipated material material (8% in biomass against 20% in nonrenewable power sources) [29]. As a result, it may be burned directly or it can be changed into various higher value fillers (strong, fluid, or vaporous) using biological, artificial, and thermal substance techniques [30]. In any case, the energy thickness of biomass is 10-40% that of most petroleum derivatives [31]. By as well as by, deposits and waste of biomass are really as still regarded to be important & often tiny wellsprings of power. Using these resources in the bioenergy industry is an environmentally sound way to dispose of these wastes [32].

SIMULATION METHODOLOGY [33]

The sustainable power-based framework advancement apparatus developed by the United States (US) National renewable energy laboratory (NREL) is used in this work for showcasing and leisure purposes. This micro force development programming is widely used in various going before half and half energy framework studies in various countries, and it was chosen here to construct a feasible cross breed framework for the site. It is an adaptable technology that simulates a combination of conventional and environmentally friendly powers to determine the most cost-effective design for any structure. The following information data will be provided in HOMER: electric load (essential energy demand), renewable resources (solar radiation), hydro resources, component specialised subtleties/costs, type of transportation technique, and so on [34].

DESCRIPTION OF THE SYSTEM

The system proposed in this research consists of generators (wind turbines, biomass generators, storage batteries), end users (loads), and control stations. The system is assumed to operate in standalone mode. The study was designed for a small community Leh Ladakh, India.

The scheme used in this study offers a perfect combination to ensure continuous power supply to the load. Wind turbines operate and generate electricity when subjected to wind pressures exceeding their rated speed of 8.14 m/s. The performance of the wind turbines fluctuates depending on weather conditions and may be interrupted. A biomass generator can produce a constant amount of energy regardless of the weather. This model can provide constant power, but has a built-in battery bank to make the system more economical. The battery bank can absorb changes in wind turbine power generation. This allows the biomass generator to continue operating even if the wind turbine cannot generate electricity. In addition, the battery can handle light loads. So a common scenario when sufficient wind pressure is available is to run the wind turbine from a battery bank. Windmills generate electricity to meet load demand, and excess and deficit energy is supplemented by batteries. If the wind turbine cannot generate power, the battery bank will handle the load if the load quality is poor. Electricity demand for household loads peaks in the evening. If the wind turbine is not running during this time, the biomass generator will start supplying the load. As the load demand decreases, depending on the state of charge of the battery, the biomass generator will continue to operate until the wind turbine starts producing electricity. The system also includes an inverter unit that converts his DC output from PV arrays and wind turbines to his AC power. A dump load that injects excess current after the load and battery charge controller have been satisfied. In this way, a reliable and sustainable energy supply is guaranteed 24 hours a day, given sufficient charge/discharge rates and capacities. The main components of the system are wind turbines, biomass generators, batteries, system balance as inverters, converters and charge controllers.

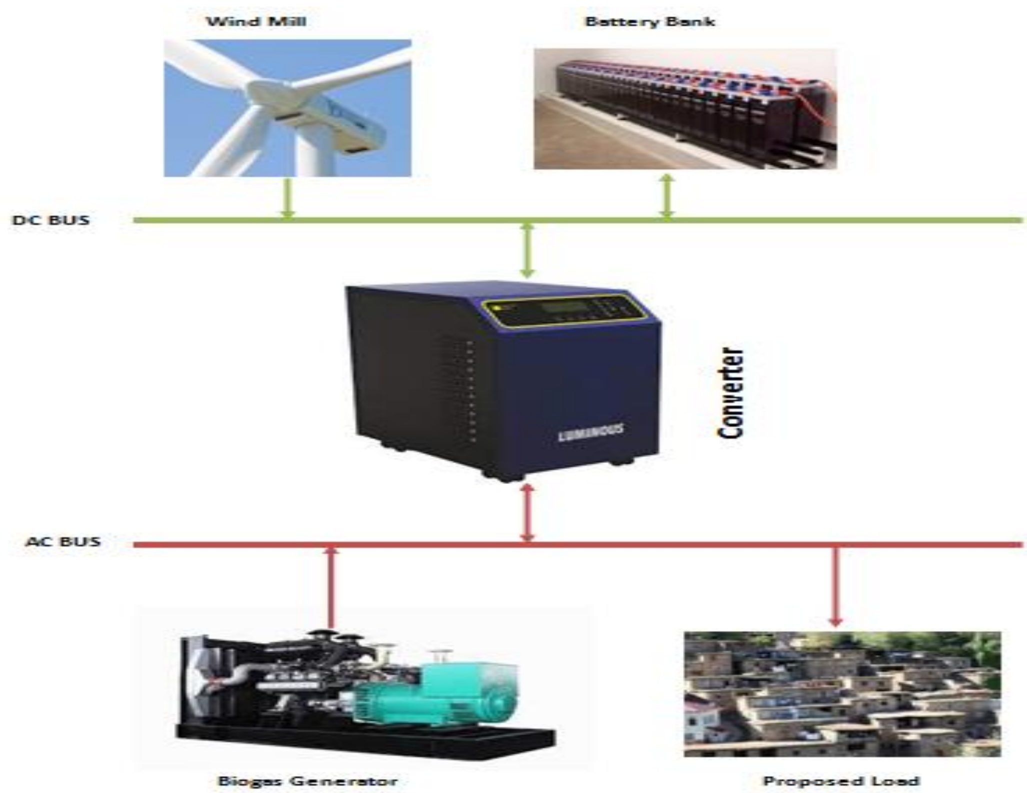

Fig.1. Wind-biomass hybrid system

LOAD PROFILE

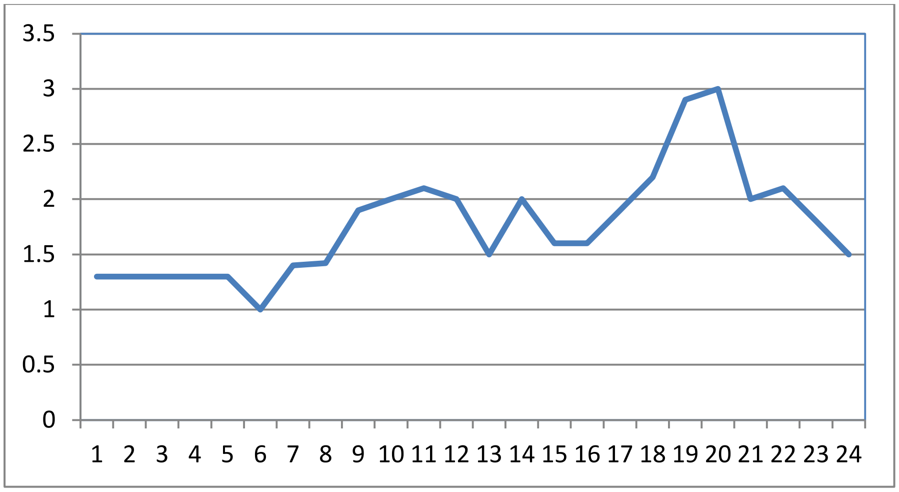

Fig.2. Average Hourly load

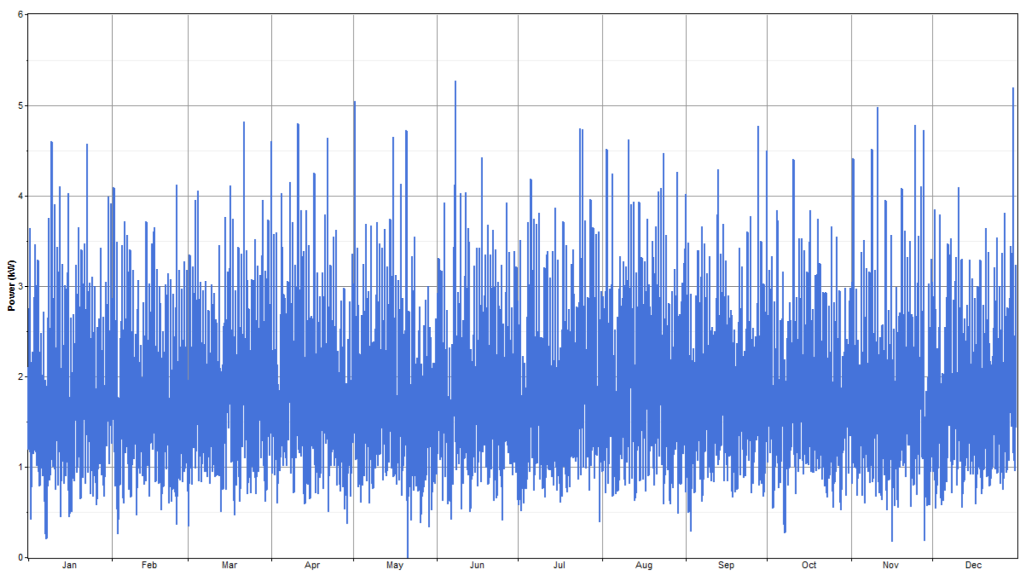

Fig.3. Hourly load variation

The proposed model aims to meet a daily load of 42 kWh with an estimated peak load of 5.3 kW. The scheme too expects that there will an increase in the present demand in near future. The model is developed to serve the basic household needs. Hence the peak load normally occurs during evening which is a normal trend. The model is synthesized using HOMER so that e reasonable and accepted model can be developed. Seasonal variation of load is not considered to make the simple. The proposed model is well balanced as the load and supply match throughout the year with a little exception.

WIND RESOURCE

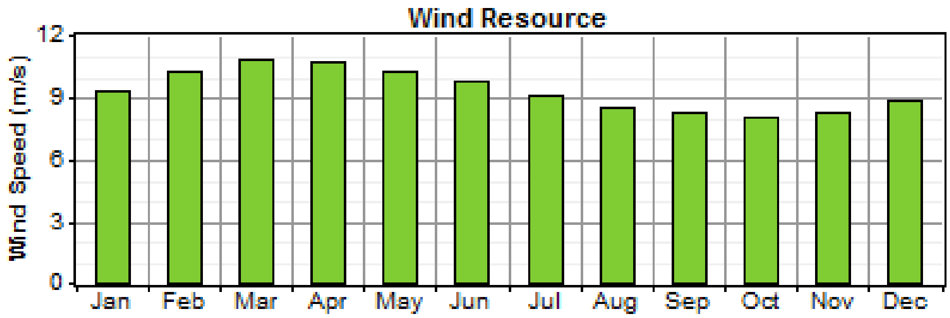

Fig.4. Wind energy resources

Windmills are one of the main sources of energy for the proposed project. A common 3 kW DC wind turbine with a nominal speed of 4 m/s is used in this study. A wind turbine has a service life of 15 years. The scale annual mean wind speed at the proposed site is 8.14 m/s. The wind turbine has an estimated capital cost of INR 2,97,000, replacement cost of INR 2,46,000 and operation and maintenance cost of INR 4,998.

BIOMASS RESOURCE

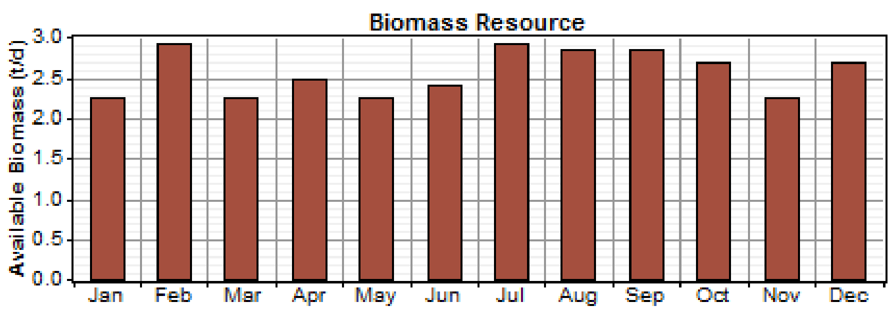

Fig.5. Biomass resource

A biomass generator is a weather-independent resource included in the proposed system. The proposed site has sufficient biomass resources, as most people have livestock, one of her main sources of income. In addition to biodegradable waste such as food leftovers and leftovers, there is also waste from agriculture. Capital cost for 3kw biomass generator (including gasifier and generator) is INR 1,59,000 and INR 1,26,000 have been allocated for replacement of biomass generators, which also incur operating costs of 12 INR/h. This cost includes the cost of biomass fuel collection too.

BIOMASS RESOURCE AND OUTPUT POWER

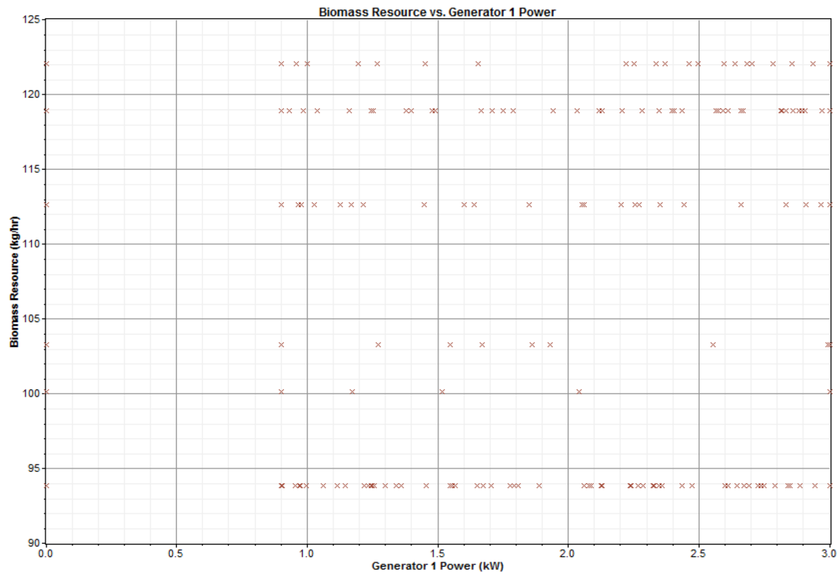

Fig.6. Biomass resource and output power

The figure above shows the power generation when biomass is available. It can be seen that the maximum production capacity is 3 kW, the operational life time is 16 years with the current load sharing ratio, which is merely 9% in this case. The biomass generator works in optimized mode. Forced shutdown and startup are not considered to make the model simple and competitive.

WIND SPEED AND WIND POWER

Wind turbines produce electricity depending on the available wind pressure. The site has moderate wind speeds throughout the year. The installed windmill has a speed of 8.0 to 10.8 m/s. The installed wind turbine is a typical 3kW wind turbine with a nominal output of 3kW DC. .

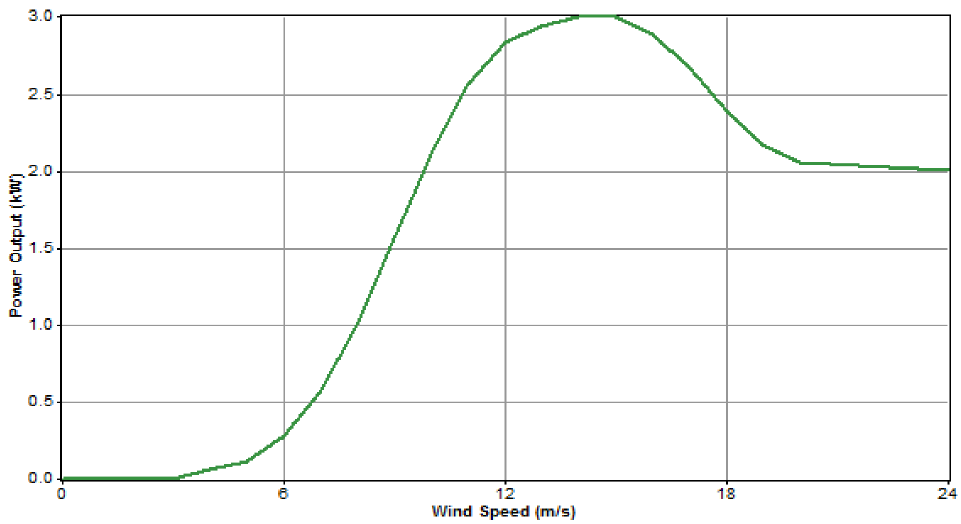

Fig.7. Wind speed and output power

BIOMASS ENERGY

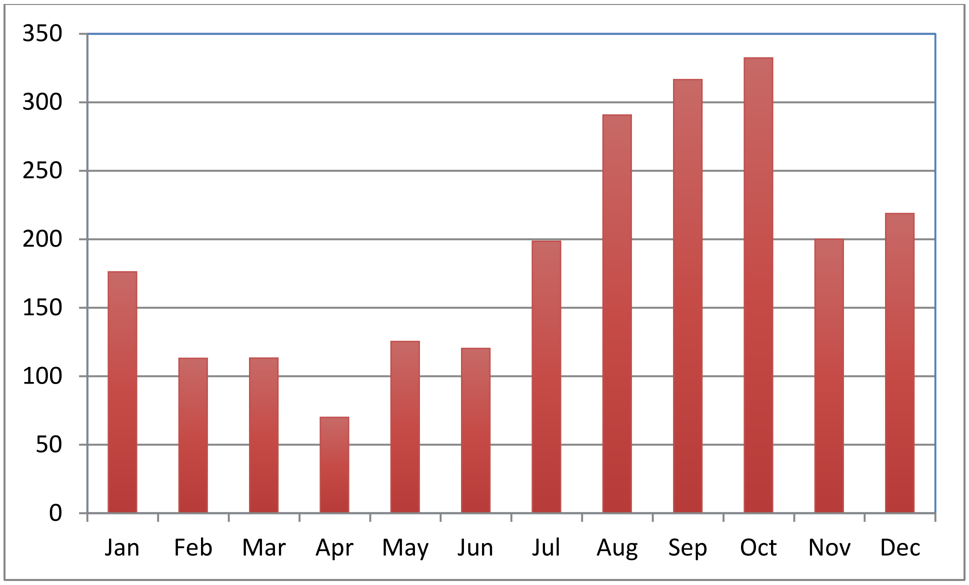

Fig.8. Biomass generator power output

The suggested location is in India's Leh Ladakh. The concept recommended reusing existing wet waste, such as food scraps, home trash from feed residue, and other wet waste, such as cow manure and other animal wastes. Waste is collected, gasified, and then sent through a generator to generate power. This model demonstrates that there is enough wet waste available for electricity generation all year. The biomass generator generates 2,274 kWh of power each year. This model uses 49 tons of bio-materials per year and operates for 940 hours per year.

WIND OUTPUT POWER

The site has moderate wind speeds throughout the year. The software estimates that the windmill will generate 24,309 kWh per year. The study states that wind turbines and biomass generators have complementary properties. The wind turbine operates 7,982 hours per year and costs 0.953 INR/kWh.

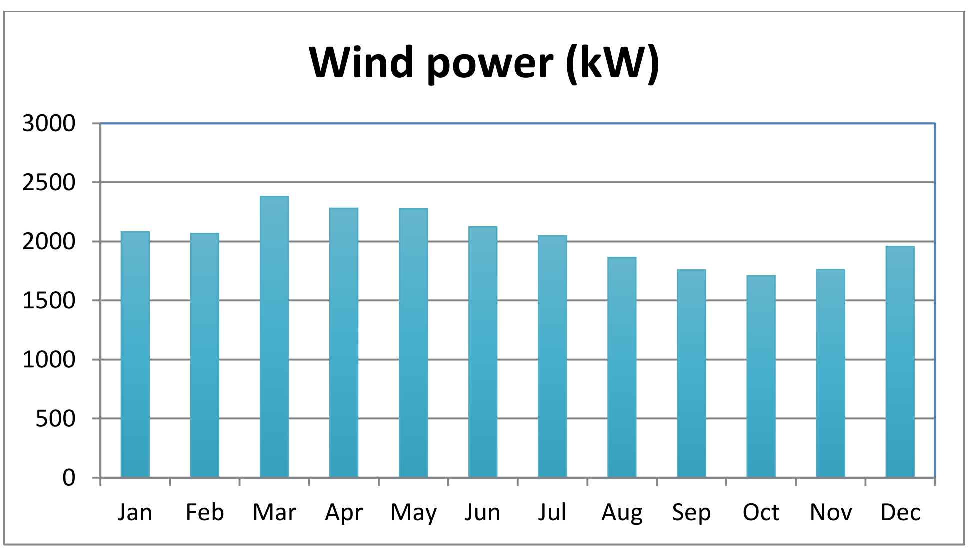

Fig.9. Wind mill power output

BATTERY OUTPUT

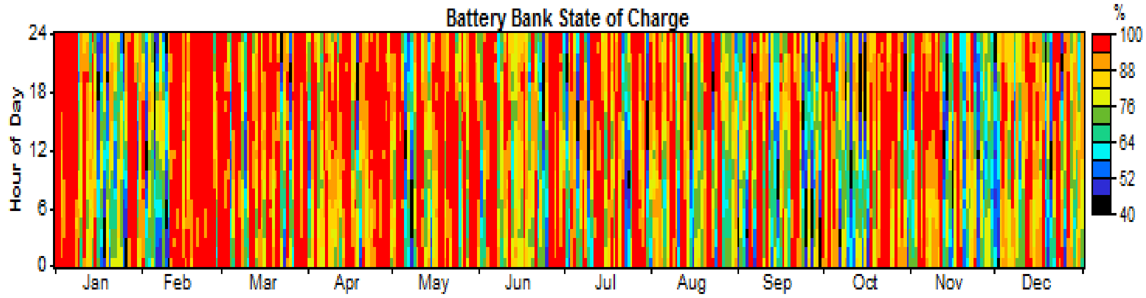

Fig.10 Battery state of charge

Depending on the system design, the battery can act as a secondary power source. Absorbs excess energy during operation of wind turbines and/or biomass generators. Batteries balance energy flow by regulating energy demand and energy production. A charge controller is used to control the battery unit. The battery has a nominal capacity of 76 kWh, HOMER calculates a nominal usable capacity of 45.6 kWh and an annual throughput of the battery of 5,516 kWh/year with 26 hours of autonomy and 5 kWh/year storage depletion.

BATTERY SOC VARIATION WITH LOAD

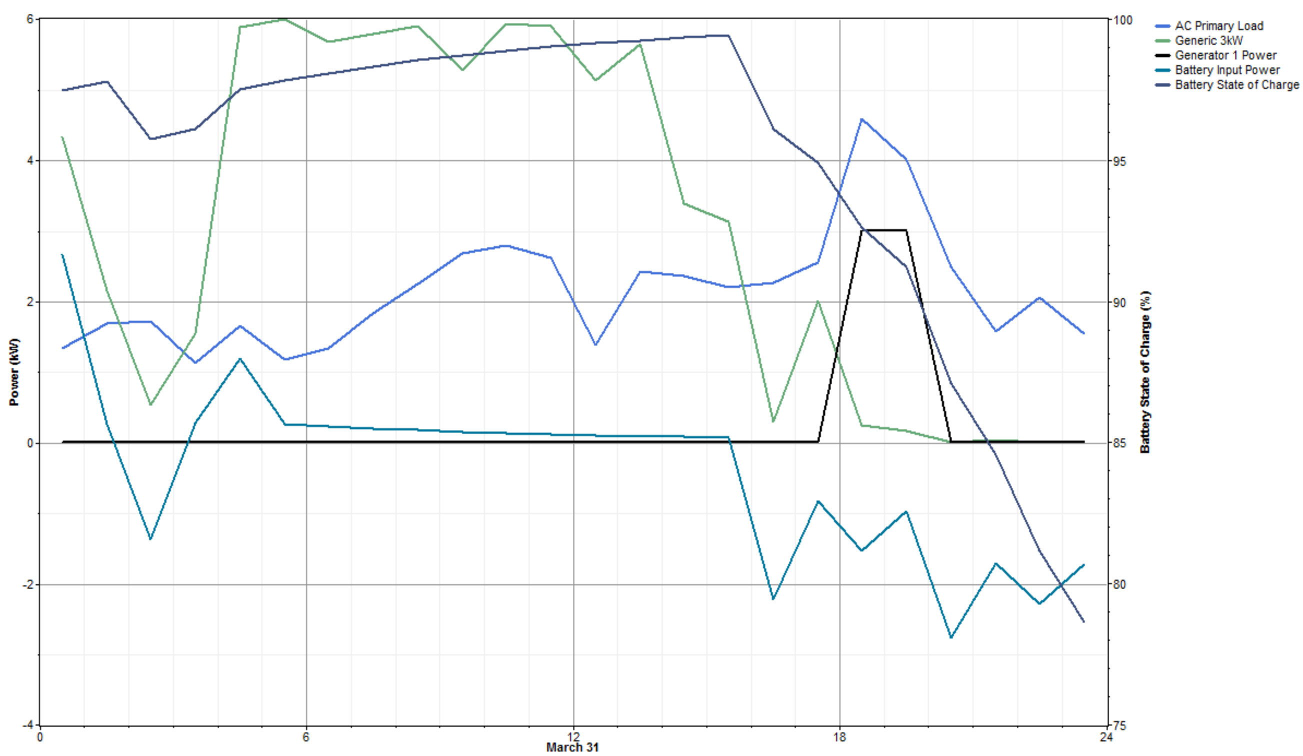

Fig.11. Battery SoC variation

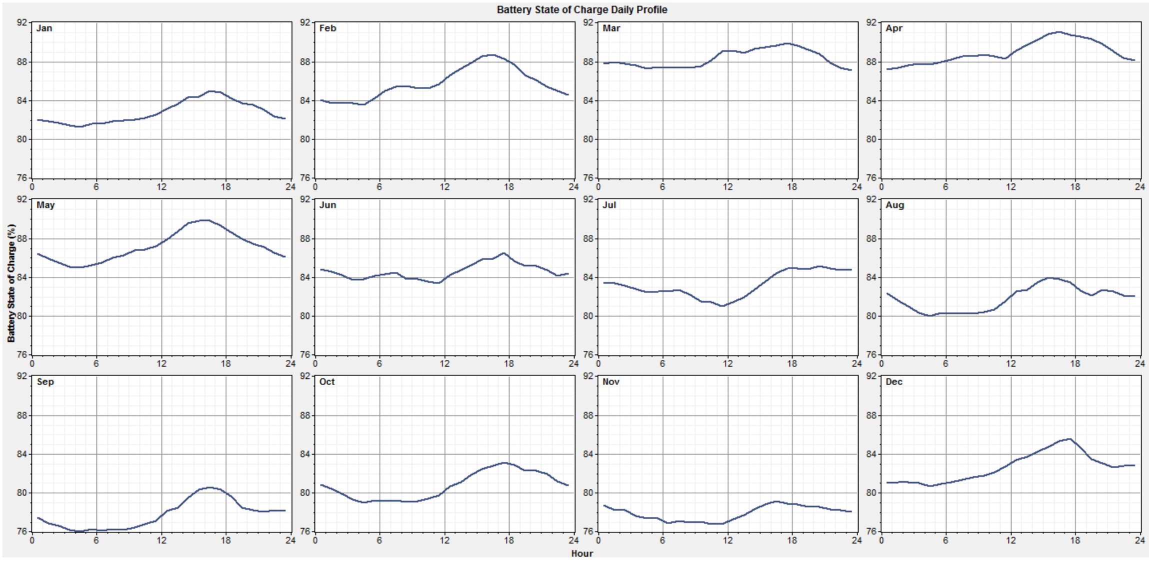

Fig.12. Battery state of charge monthly variation

In the figure above, March 31st of the simulated year is shown to observe the change in the state of charge of the battery. As the load on the connected system changes from moment to moment, the performance of the battery will keep it in balance. The scheme presented here allows simultaneous charging and discharging of a battery bank. The study shows that a lower load demand increases the battery's SoC, since some of the power generated by the wind turbine and biogas generator is used to charge the battery. And when wind power is less than its rated capacity, a reversal occurs. The SoC also varies depending on the biomass operation. The following figure shows the monthly variation of Soc. .

DAILY MEAN ENERGY PRODUCTION AND LOAD DEMAND

The main sources of the proposed system are wind turbines and biomass. The system consists of a 2 kW wind turbine and a 3 kW biomass generator. Wind turbines cover 91% of the load and biomass supplies 9% of the load respectively. Source and load profiling allow the largest portion of the load to be handled, giving you achievable properties. Orange bars show energy production from biomass, blue bars show wind turbine energy production for each month, and green lines show planned load averages on the proposed model.

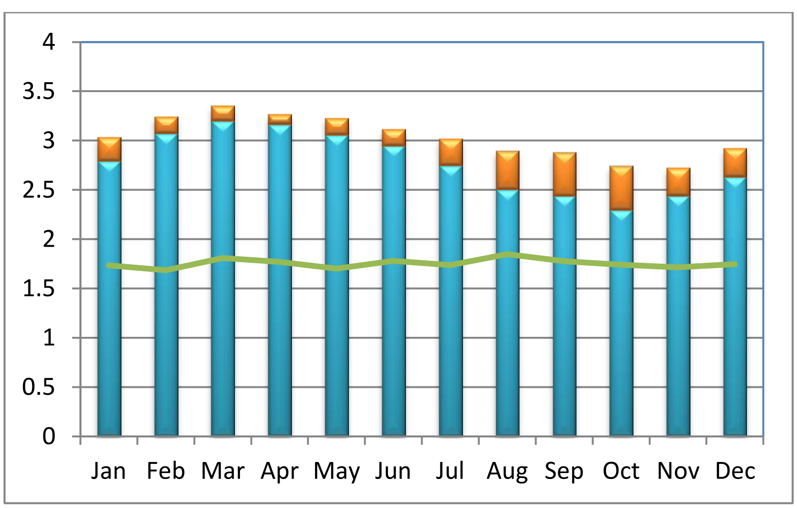

Fig. 13 Daily mean energy production and load demand

EFFECT OF BATTERY INTEGRATION

It can be observed that the load of all power grids connected to either private or commercial consumers changes at every given moment. As the load changes, so must the power supply to keep the system running smoothly. In the proposed system, electricity is generated by wind turbines and biomass generators and supplied as backup by a battery bank. Wind turbine output is inherently unstable as it depends on the weather. To accommodate changes in load demand, the battery power must change accordingly.

Here we can also observe that as the load changes, the input and output of the battery change to match the demand of the load. The system is equipped with a charge controller that controls the charging or discharging of the battery. Real-time operation of the charge controller synchronized with the battery bank provides a smooth load curve.

ENERGY CONSUMPTION OF FOUR TYPICAL DAYS IN A YEAR

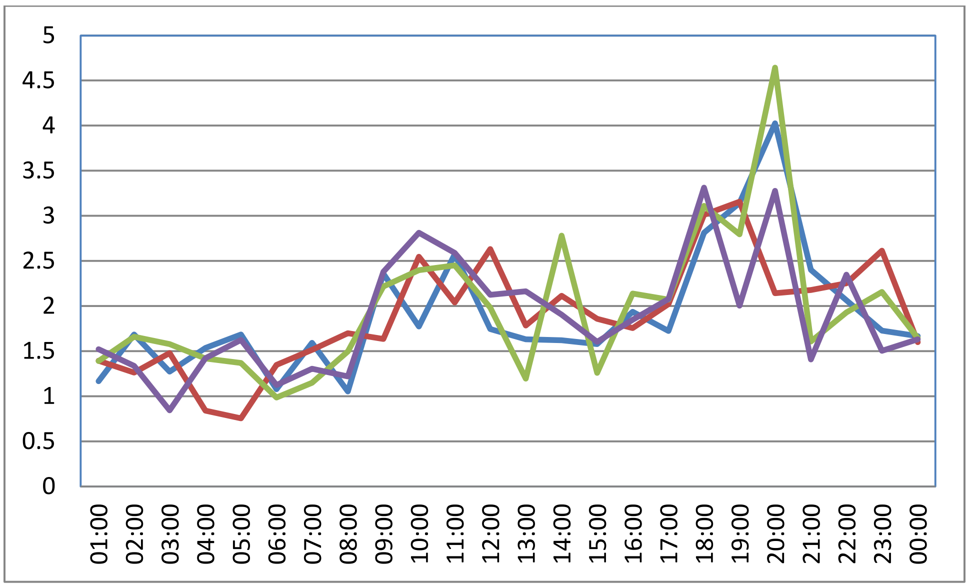

Fig.14 Electricity consumption of four typical days in a year

Electricity consumption at the proposed location is estimated at 42 kWh/day. The figure above shows an example load profile for four different seasons. March 15th is taken as a typical day representing the spring season (marked by the red line), and similarly for summer May 15th is taken as the summer season (marked by the green line), August 15 represents the monsoon season (indicated by the violet line) and January 15 represents the winter season (indicated by the blue line). Since only domestic loads are considered, peak load demand occurs in the evenings throughout the year.

HOURLY ENERGY BALANCE OF THE PROPOSED SYSTEM

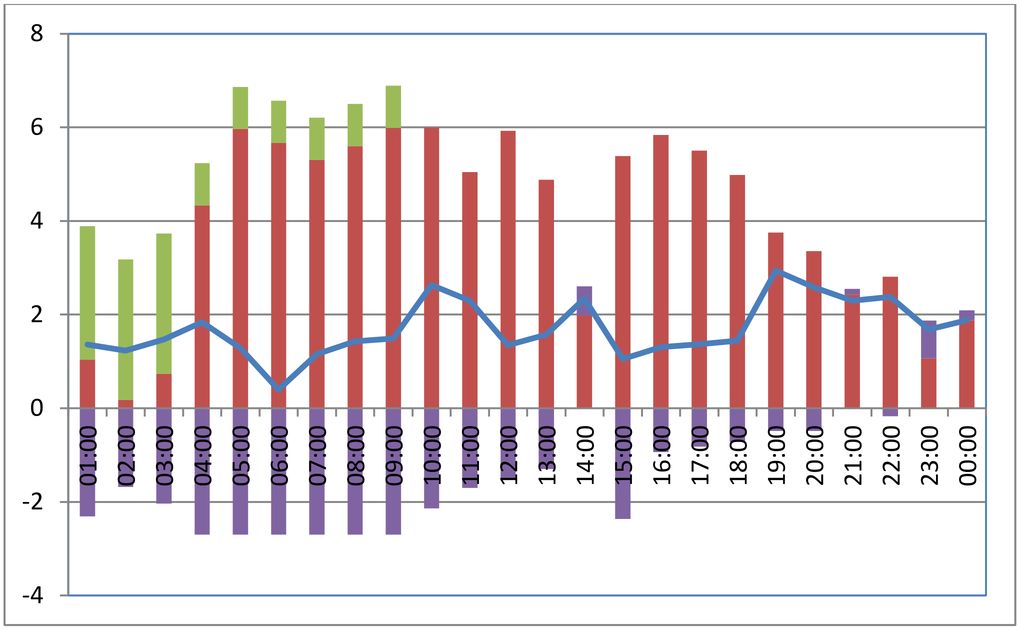

Fig.15 Hourly energy balance

The graph below depicts an example of hourly simulation results for July 31st. An examination of the proposed system's energy balance. The system is meant to fulfill normal load demands using power from wind turbines and biogas energy, with extra energy stored in battery units. To compensate for the windmill's intermittent nature, the battery bank charges and discharges continually throughout the day. Biomass generators only operate when there is an energy shortfall that cannot be met by a windmill or a battery-windmill hybrid operation. The functioning and energy production of biomass generators alter in response to variations in wind energy. The violet bar represents the battery power exchange, the red bar represents the wind mill energy output and its hourly fluctuation, the green bar represents the energy production from the biogas generator, and the blue line represents the average hourly load.

RENEWABLE PENETRATION LEVEL

A feature of the proposed system is the degree of penetration of renewable energy. The proposed system uses wind turbines and biomass to generate electricity, all of which are renewable in nature. The proposed system can achieve approximately 100% of its power production from renewable sources, ignoring the power consumed in the production of the system's main components and other ancillaries.

SPIDER GRAPH

Spider charts are used to display sensitivity results. It discusses the relationship between biomass generators, wind turbines, converter energy their capital costs, along with thier replacement costs. With decline in the cost of wind turbines, the energy cost will drop to INR 4.87 per unit. Other costs also affect energy price reductions, but to a relatively small extent.

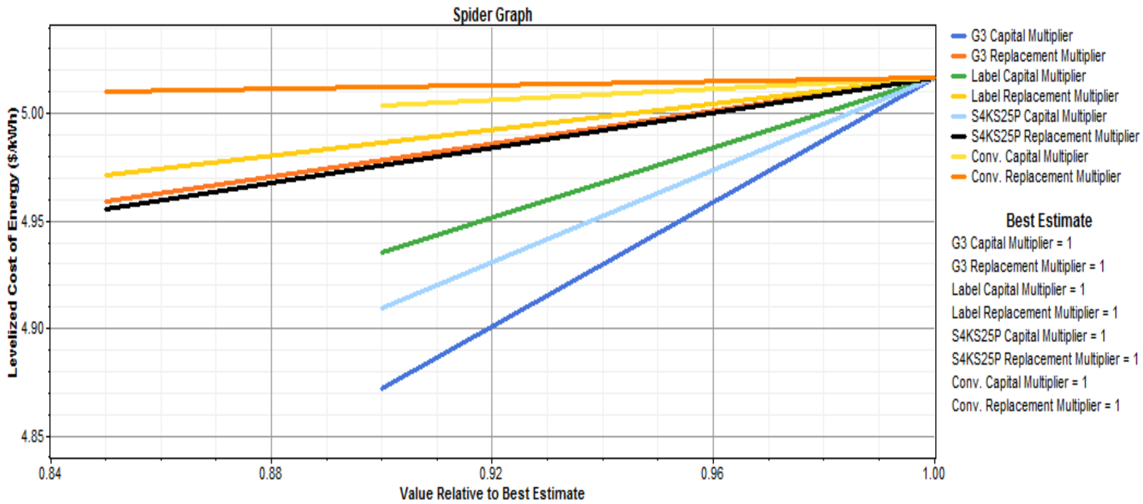

Fig.16. Surface plot of electricity charge

ECONOMIC ANALYSIS

The below figure depicts the overall optimization outcome of the hybrid system obtained by the HOMER program. Each table row represents a feasible system configuration. The first four columns display an icon, the following four columns display the quantity or size of each component, and the last seven columns provide critical simulation findings such as the system's initial capital cost, operating cost, net present cost, levelized cost of COE, renewable percentage, biomass, and label. The best design is the one with the lowest NPC, which includes a 2 kW windmill, a 3 kW biomass generator, 10 number of S4KS2P battery banks, and a 4 kW converter. The original capital cost is INR 5,92,200, the annual operating cost is INR 30,56, and the total NPC is INR 985,365. The COE is determined to be 5.016/kWh with a 100% renewable percentage.

G3	Label (kW)	S4KS25P	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Biomass (t)	Label (hrs)
2	3	10	4	$ 592,200	30,756	$ 985,365	5.016	1.00	49	940
2	3	8	4	$ 550,200	34,057	$ 985,565	5.017	1.00	59	1,198
3	2	8	4	$ 596,200	30,510	$ 986,223	5.023	1.00	36	1,117
3	2	10	4	$ 638,200	28,870	$ 1,007,255	5.129	1.00	29	864
2	3	5	4	$ 487,200	43,867	$ 1,047,971	5.335	1.00	79	1,800
3	3	8	4	$ 649,200	31,227	$ 1,048,383	5.337	1.00	41	853
2	4	10	4	$ 645,200	31,964	$ 1,053,811	5.365	1.00	53	808
2	4	8	4	$ 603,200	35,736	$ 1,060,028	5.396	1.00	61	1,013
3	3	10	4	$ 691,200	29,615	$ 1,069,775	5.446	1.00	33	694
3	3	5	4	$ 586,200	38,943	$ 1,084,020	5.520	1.00	59	1,364

Fig.17. Optimization result of Wind-Biomass Hybrid System

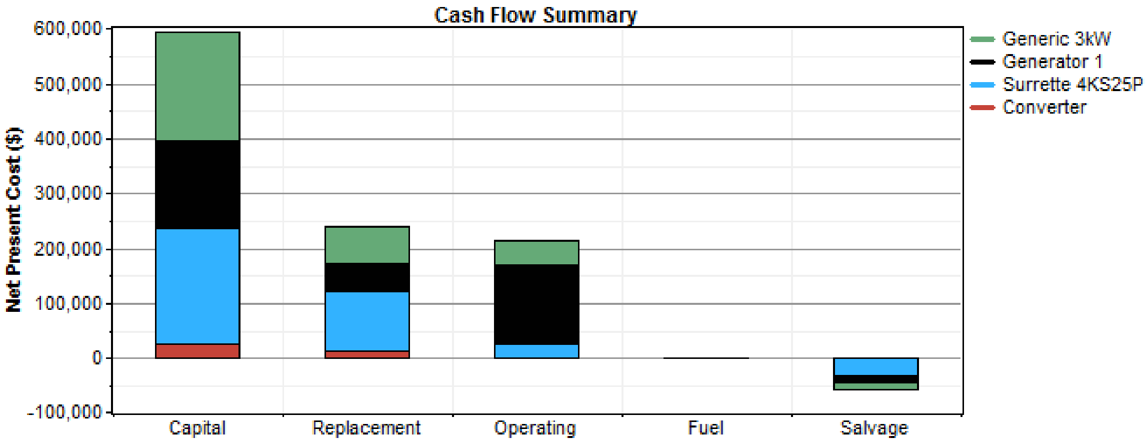

Fig.18. Cash flow outline of the project

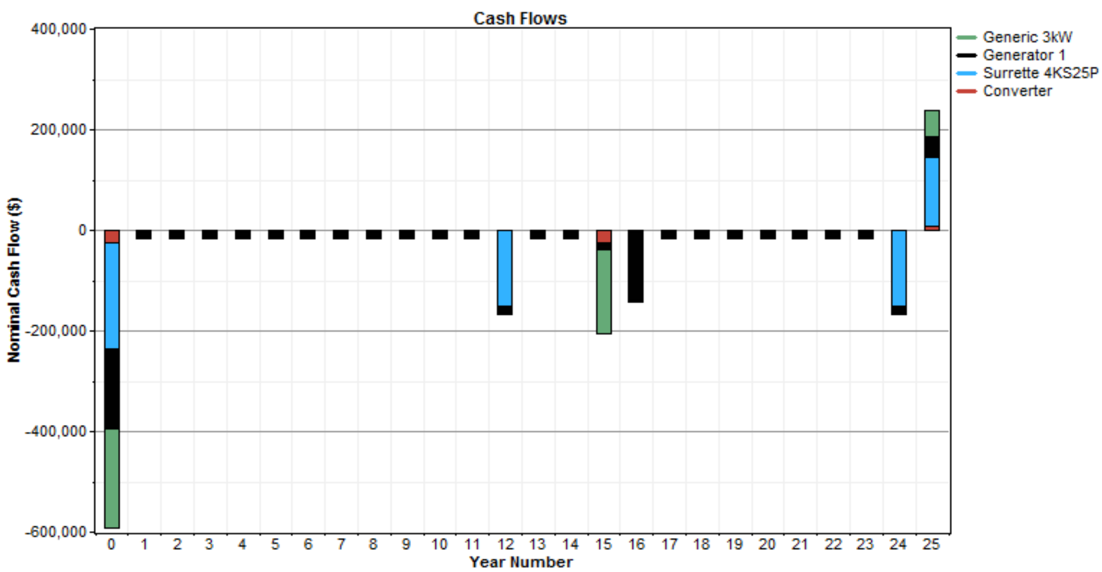

Fig.19. Cash flow information of the scheme

The graphic above depicts the yearly cash flow over the life of the gadget. Individual bars in the graph may indicate the total cash flow or the total cash flow for a specific season. The first bar in season zero represents the product's capital cost. The figures below show run-off (expense) as a result of equipment replacement or perhaps operation and maintenance. Generators should be changed every 16 seasons, general purpose 3 kW wind turbines after 15 seasons, converters every 15 seasons, and batteries every 12 . A good return signifies an inflow and might be a return on the residual value of the project's equipment at the end of its useful life.

CONCLUSION

The viability of a Wind-Biogas hybrid system for a community load is investigated in this study. It concludes that with the integration of such system, the system's power output will increase, there will be no shortage of capacity, which will greatly improve system reliability, and the levilised cost of energy is 5.016 INR/kWh, which may decrease in the near future as the costs of such system are declining. The outcome demonstrates that the system is viable and appropriate for the proposed site, with the potential to electrify such an area with enough supply and maximize the use of renewable sources existing on the site. The technology is also environmentally friendly and consequently recommended.

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