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Alternate power generation by hybridization model of SPV/Wind/Biomass

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Abstract: Ladakh, situated in the high-altitude Himalayan region, faces unique challenges in meeting its power demands due to extreme weather conditions and geographic isolation. This study investigates the feasibility and optimization of an alternate power generation system tailored for Ladakh, utilizing a hybrid model of Solar Photovoltaic (SPV), Wind, and Biomass energy sources. The research employs the Hybrid Optimization Model for Electric Renewables (HOMER) to design a customized solution that addresses Ladakh's specific energy needs. The hybrid system integrates SPV arrays to harness abundant solar radiation, wind turbines to capture wind energy in the high-altitude terrain, and biomass generators fueled by locally available organic materials. The HOMER software is utilized to analyze the techno-economic aspects of the hybrid system, considering Ladakh's unique environmental and geographical factors. Through comprehensive simulations, the study aims to determine the optimal configuration that maximizes energy output while considering the intermittency of renewable sources and the region's energy demand variability. The research also explores the economic viability of the proposed hybrid model, taking into account the upfront costs, maintenance, and potential savings in fuel expenses. The outcomes of this study provide valuable insights into the design and implementation of a hybrid renewable energy system specifically tailored for Ladakh's challenging conditions. The proposed solution holds the potential to enhance energy resilience, reduce dependence on conventional fuels, and contribute to sustainable development in this remote and environmentally sensitive region.

INTRODUCTION

Humans require energy to survive. A secure, sufficient, and open supply of energy is critical for the survival of present societies. As the world's population grows, so, too, does the demand [1]. Energy exists in numerous forms, including mechanical energy, nuclear power, electrical energy, hydro energy, and so on. Of all types of energy, electrical energy is the most well-known because to its ease of use in the workplace. In contrast to other forms of energy, it is not needed that energy be created (changed) and used in the same location. It is often transported some distance from the point of use. It is also highly quiet and speedy [2].

The need for energy is always increasing, yet the source from which these energy systems operate has a wide range of variance [3]. According to the World Energy Forum, the fossil reserves will be depleted within the next 100 years. Because they produce the majority of the energy, the energy industry will suffer [4].

When it comes to global energy generation, traditional sources such as diesel-based nuclear power plants, coal-based nuclear power plants, atomic-based nuclear power plants, and hydroelectric power plants dominate. According to RENs, renewable energy now supplies 19% of load and is expected to grow in the future [5]. Autonomous renewable energy systems (RESs) have earned recognition for being endless, environmentally safe, reliable, competent, and feasible, and hence appear to be lucrative. Furthermore, energy from renewable sources is critical to the future development [6-8]. PV innovation is abundant and free of risk from pollution, with several notable advantages over traditional power-generation systems. Most significantly, solar energy is the world's most ecologically benign source of power. The Sun may generate PV force anywhere in calm or tropical climates, in urban or rural settings [9]. Solar PV technology has received much-needed attention. The new study reduced the cost of PV. PV systems are predicted to be viable and lucrative [10].

Wind energy generation is gaining popularity for a variety of reasons. It is advantageous to utilize a wind turbine when the wind pressure is within the windmill's operational range [11].Wind power potential is difficult to measure since, unlike solar power, it relies on site characteristics and geographical location in generally, as wind speeds are obviously impacted by neighboring physical and geographical factors [12].

Timber, farm waste, home wet garbage, food residue, and animal manure are all examples of biomass energy sources. It is widely distributed across India. A large amount of energy may be produced by properly processing these resources. Waste disposal has the potential to be used as a source of energy generation [13]. India has a high population, which generates a large volume of bio waste that may be used. By utilizing bio gasification, this bio waste may be exploited as a source of energy generation [14]. The garbage generated by Indian families frequently caused disposal issues. Municipal solid garbage comprises a significant quantity of bio matter. These can be converted into energy in a variety of ways [15]. Biofuel, biodiesel, and other crops are bringing new life to biomass. Furthermore, waste treatment has a great potential for such energy [16].

The disadvantage of the SPV-wind integrated system is that it cannot be made dependable without battery storage. Many storage alternatives are available, some study suggests super capacitors, some offer hydro on a tiny scale, and only integration will work as a dependable source [17]. Many studies have concluded that biomass is more visible and practicable in a nation like India, which has a large agricultural basis [18]. Biomass is not sophisticated, but it must go through phases [19]. Biomass is used in conjunction with PV and windmill operation. This technology has the potential to alter the game by creating massive amounts of electricity [20, 21].

There exist several elements that contribute to such a difficult situation in the context of supply of electricity. The main consideration is the geographical location. The site for this study is Leh in the Ladakh Union Territory. Geographically, the location does not allow for grid supply of electricity. On the other hand, various studies have revealed that this location has a lot of potential in terms of renewable energy particularly solar energy. Wind energy can also be used to assist the solar system. These energies have the potential to successfully resolve the problem. However, because these two energy sources are intermittent, combining them may result in a loss of dependability. A third power producer is deployed to increase supply dependability and overall power generation by acting independently of the weather. As a result, the study's plan includes a biogas generator. Solar PV-wind with biogas generator integration is the proposed concept. A battery bank is included as a source of backup energy to make the system economically viable.

Consequently, the current study aims to introduce the Solar PV-wind-biomass hybrid model and investigate the hybrid alternative for dependable, continuous, and affordable supply of electricity for the mentioned load.

LITERATURE REVIEW

Behura et.al (2021) presented that Solar photovoltaic (PV) systems are utilized all over the world to generate clean power. The solar system erected on the rooftop of the G.D. Naidu Block at Vellore Institute of Technology (Vellore, India) is described in this paper. In order to increase the energy efficiency of an existing PV system, a unique PV plant design is designed here [22]. Kumar et al. (2020), observed that solar energy is a rapidly growing source of energy all over the world. The total installed solar power capacity in India is 34811.78 MW as of April 30, 2020. This article describes the analysis of load requirements at the mechanical department office at the engineering college in Bikaner, as well as the design and construction of a standalone solar PV system [23]. Sreenath et al. (2019), explains that the use of Renewable Energy (RE)-based energy production for airport operations can reduce atmospheric pollution from the aviation sector. The solar PV system is the most appropriate RE technology for the airport area [24]. R. Sitharthan et al. (2018) investigate how increased awareness of environmental change has compelled several nations to employ Renewable Energy Resources (RER) for electricity generation. Wind energy accounts for around 28% of global energy demand. India is one of the countries that is utilizing wind power potential with the ultimate objective of achieving power age. It also covers the public authority's major emphasis on endowments and observable methods to increase wind power utilization by the public authority [25]. According to P K Chaurasiya et al. (2019), India is endowed with massive sustainable power assets in general, and wind energy assets in particular. Assessing the capabilities of wind energy assets in improving the country's energy status is critical for the development of wind turbine installations in the not-too-distant future [26]. According to Jain et al. (2020), with rising worries about climate change and energy security, the Government of India plans to increase the percentage of solar and wind-based Renewable Energy (RE) in the energy mix [27]. According to Usmani (2020), the purpose of this study is to quantify the biomass potential in India. As a result, calculating the quantity of biomass and its potential for energy and biofuel generation is required. According to this analysis, policies that encourage demand generation, investment security through risk insurance, and subsidies will be beneficial for harvesting India's biomass potential [28]. Kumar et al. (2015) examine the government of India's biomass energy system, for which the article assesses different parameters. The article also analyzed the approach of the legislation to the subject [29]. Singh et al. (2020), explains that open burning is the cheapest and easiest technique for farmers in many countries to remove big quantities of generated rice straw without generating environmental contamination.

Finding a sustainable rice straw management strategy is so critical. The use of rice straw as a priority in current hybrid power production systems has not yet been examined. To meet this demand, this paper presents the design and techno-economic assessment of a small-scale rice straw-based microgrid that uses waste rice straw from a hamlet of 250 houses and 900 acres of farmed land to generate electricity [30]. Malik et al. (2021) stated how India has a plentiful supply of renewables to contribute to the energy industry. In this paper, a techno-economic and environmental analysis of an off-grid hybrid system in the western Himalayan area is performed as a case study. Malik et al. (2021) stated how India has a plentiful supply of renewables to contribute to the energy industry. In this paper, a techno-economic and environmental analysis of an off-grid hybrid system in the western Himalayan area is performed as a case study [31]. Singh et al. (2016) discuss the relevance of renewable energy sources and how governments are interested in adopting them. Solar PV, wind, and biomass are becoming more popular for generating power in remote places. The research assesses the performance of a solar-wind-biomass integrated scheme developed for a specific location. The honeybee settlement approach is used in the study, and the scheme is simulated using HOMER [31].

METHDOLOGY USED

The US NREL lab created the Hybrid optimization model for electric renewable (HOMER) [32], which is employed in this work to simulate the proposed scheme. The HOMER is capable of modeling various renewable and nonrenewable energy sources, and the load may be precisely evaluated by combining the unpredictability of day and time step. In the simulation, HOMER employs both conventional and non-traditional energy sources as needed. The simulation generates dependability statistics, which may be evaluated to determine the scheme's practicality and economic viability [33].

DESCRIPTION OF THE SYSTEM

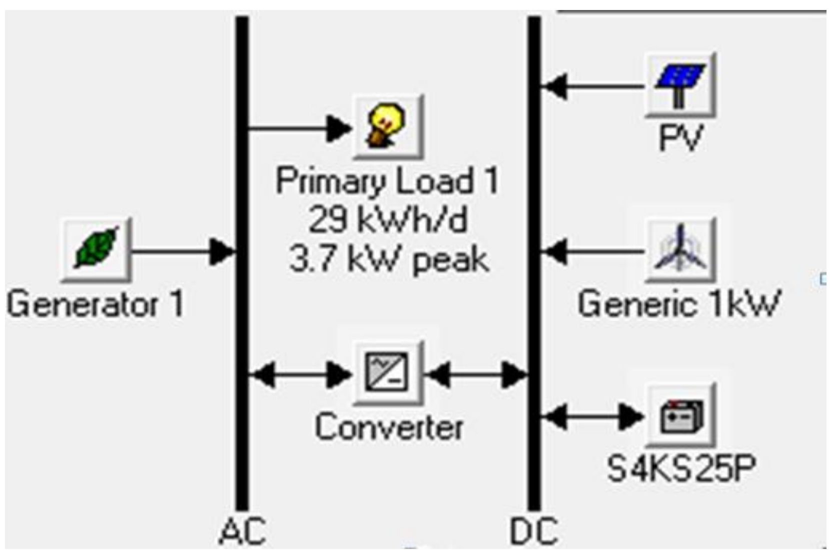

Fig. 1 PV-Wind-Biomass hybrid system

The system's primary sources include solar energy, wind turbines, and biomass, with battery backup in cascades, a load model for servicing, and a command and control unit. The system is thought to be running in standalone mode. The research was intended to take place in the Indian state of Ladakh's Leh Union Territory.

To fulfill the majority of load demand, the system attempts to balance independent and weather-dependent renewable sources. Solar photovoltaic and wind turbines provide power during the day and when there is a strong breeze. When there is surplus energy after fulfilling the charging need, it will charge the battery, which may be utilized when there is a power outage. If the need arises in the evening, biomass generators typically work at set hours. If wind power is uninterruptible and batteries are available, the biomass will not operate that evening. In the model, the converter discovers an application. A dump load is used to supply extra power after it has passed through the charge controller and charged the battery. The PV array, wind mill, biomass generator, battery, and balance of system components such as inverter, converter, and charge controller are the key components of the system.

LOAD STUDY

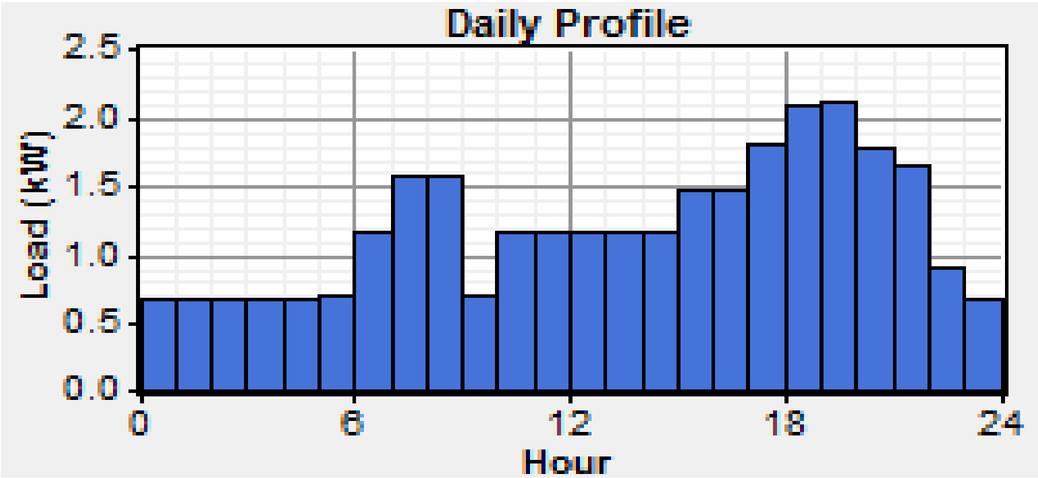

Fig. 2 Daily Average Load

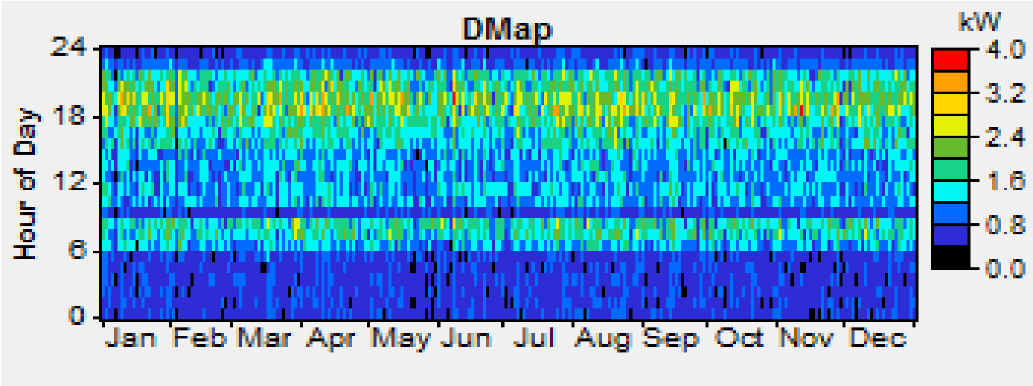

Fig. 3 DMap of Load Profile

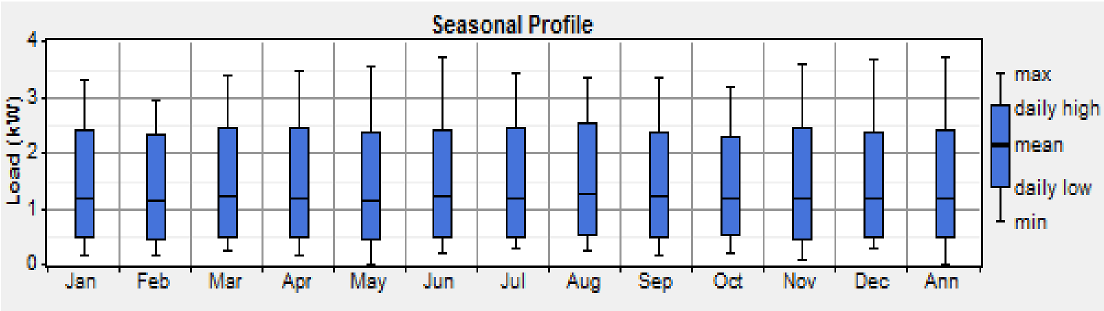

Fig. 4 Seasonal profile of Load Profile

The load profile is the main design element for the schematic. Loads include a number of domestic homes and are equipped with a number of devices that have different devices and different application times. However, the loads were not measured on site due to various limitations and instead the focus was shifted to simulation, thus, based on national average energy consumption and load pattern observations, designed load. Simulation was then done through using HOMER. For simplicity, seasonal variation of load was limited. The system serves a daily load of 29 kWh and a maximum load of up to 3.7 kW.

SOLAR ENERGY RESOURCE

Solar energy is one of the main energy sources of the developed system. The electricity production of a photovoltaic generator depends on the weather conditions in which it is installed. The study was conducted at 34.35 degrees latitude and 77.4 degrees longitude. And for the proposed site's monthly mean solar irradiance of 5.46 kWh/m2/day with a clarity index of 0.652, the installed capacity of the photovoltaic array is 1 kWP.

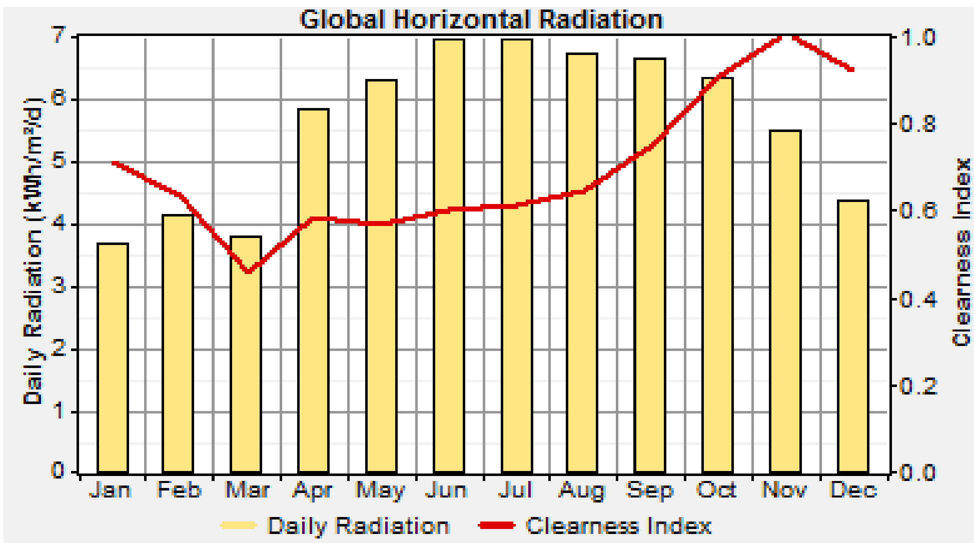

Fig. 5 Solar energy resources

In this proposed scheme the capital cost for the 1 kWP PV array is taken as INR 83000 and all other cost are zero.

WIND RESOURCE

Wind resources are included in the proposed model to exploit the energy contained in the wind. In this study, the wind turbine was kept for testing purposes only, so the size of the turbine was limited to about 1 kW, the general 1 kW model was chosen for this purpose. The estimated life of the wind turbine is 15 years. The location measured the average wind speed of 3,817 m/s. Capital costs of INR 99,000 and operating and maintenance costs of INR 1,667/year are considered.

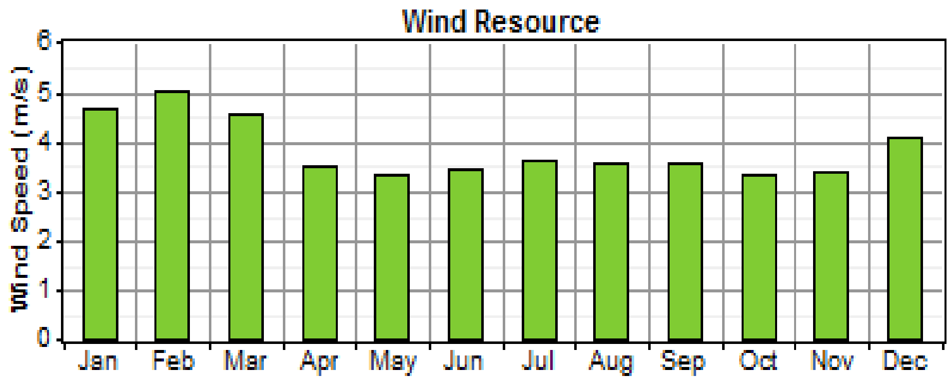

Fig. 6 Wind energy resources

BIOMASS RESOURCE

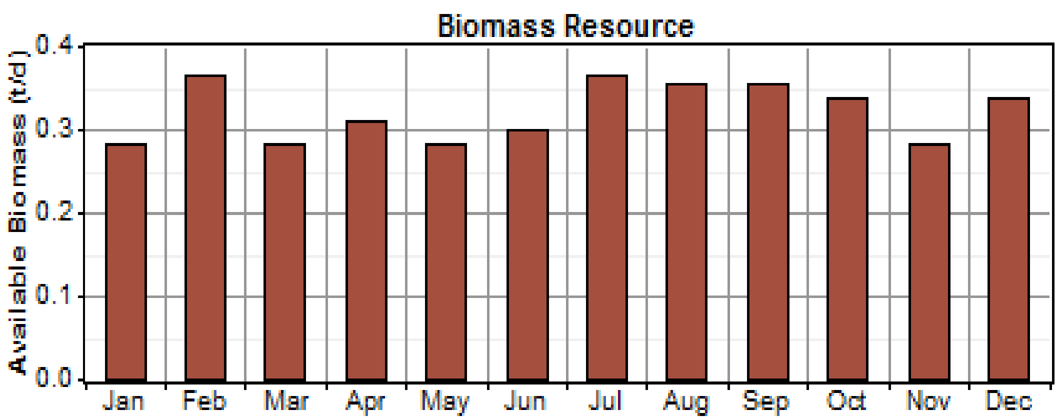

Fig. 7 Biomass resource

The biomass generator is the only resource in the proposed scheme that is independent of weather conditions. The resource shown in the figure above is an estimate that takes into account the community and its activities. Resources include feed scraps, livestock waste, agricultural waste, livestock waste, and more. This resource is unique because it is freely available. However, the resource acquisition process involves certain financial requirements, but these requirements are few and non-recurring. The investment and replacement cost of a 1 kW biomass generator (including gasifier and generator) is INR 56,000 with a life cycle of 15,000 hours.

RESULT EVALUATION

ESTIMATED POWER OUTPUT FROM SOLAR PV

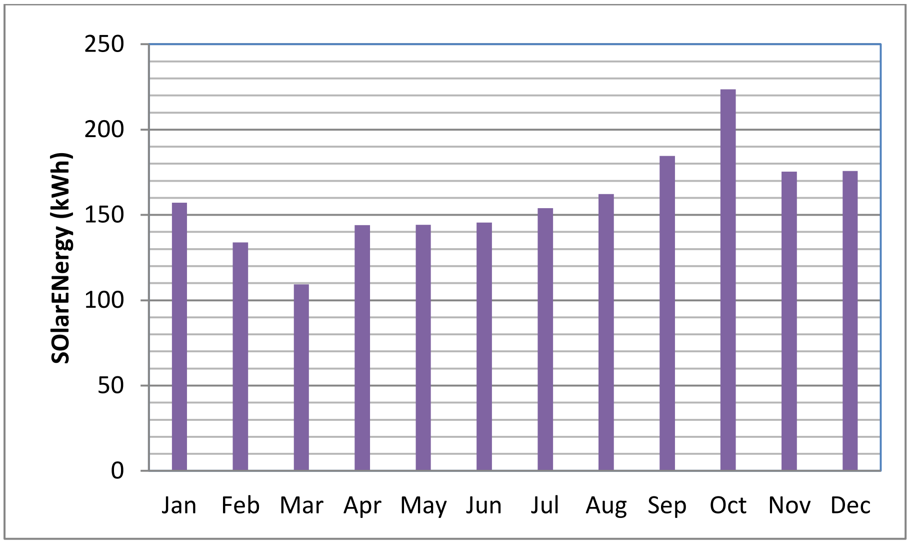

Fig. 8 Estimated power generation by PV array

This figure shows the estimated output power of the installed PV. The PV power depends on the radiation breakdown on the panel's surface as well as on the temperature. The graph observes that the monthly output varies. The highest solar power production was recorded in October due to clear skies and favorable operating temperatures. PV shares 33% of the power output in the system.

BIOMASS ENERGY

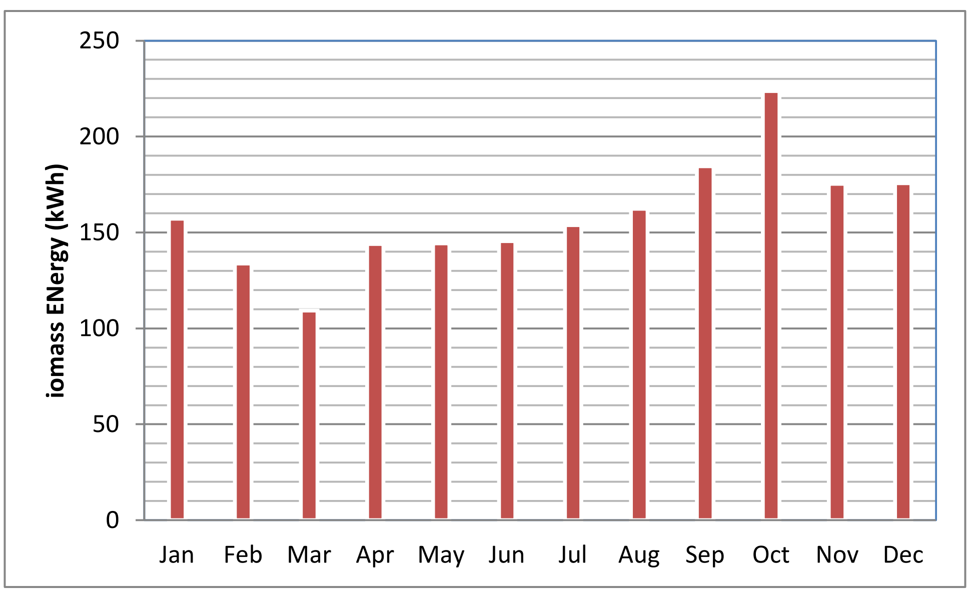

Fig. 9 Biomass generator power output

Biogas generator is one of the main energy generators of the proposed scheme. The average energy output of a biogas generator is shown in the figure below. Since the biogas generator does not fluctuate over time, it outperforms the other two types of generators in terms of generating capacity and quality of power produced. The biogas generator shares a significant portion of the energy in the system. The biomass generator produces 8538 kWh of energy on a year during its useful life.

ESTIMATED WIND POWER GENERATION

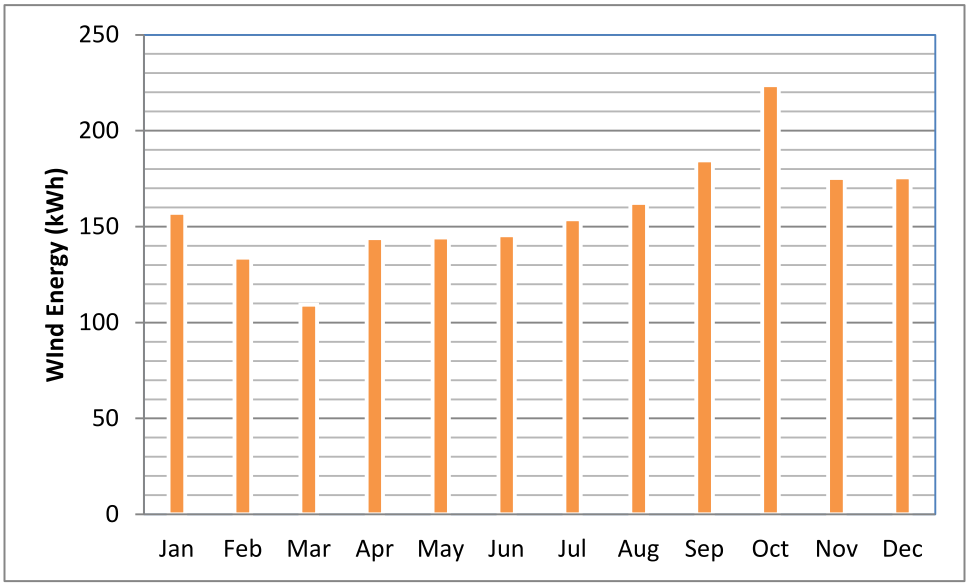

Fig. 10 Estimated output by the wind turbine

Along with two other generators, the plan also includes a windmill. But wind turbines were included in the study to examine the feasibility of such a plan. The power output and load ratio of the wind turbine in the diagram is much lower. The program also limits the size of wind turbines by installing 1 kW common wind turbines. The software estimates that the electricity produced by the wind turbine is about 2% of the estimated load.

BATTERY OUTPUT

The battery is the passive generator included in the diagram. Electricity production from solar and wind energy does not change with load demand. instead, they change depending on the weather. Therefore, batteries are included in the scheme to save energy exchange between generator and load. Excess energy is stored and used at a later stage. The battery app also optimizes the schematic. Batteries can improve the power quality of intermittent power sources and ensure that just a light battery charge is enough to fully charge in a considerable time. The software calculates the autonomy is 15.3 hours. Autonomy is optimized by software.

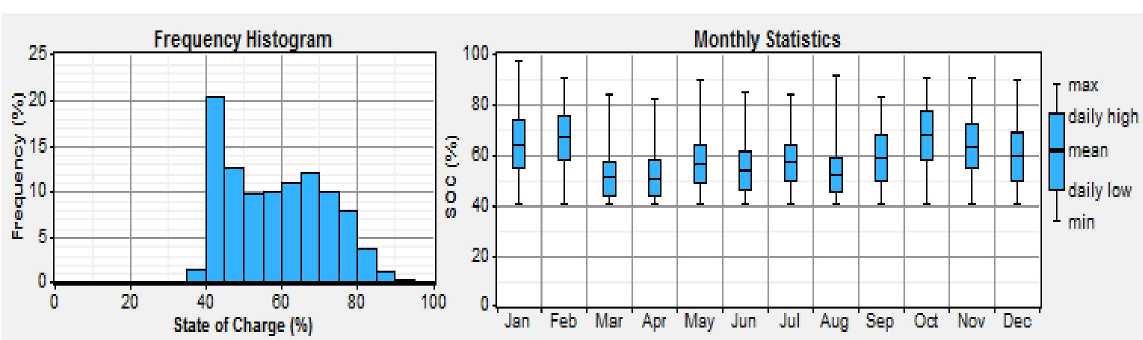

Fig. 11 Battery state of charge

BATTERY SOC VARIATION

The State of Charge or SoC provides the insight of the optimization of the scheme. The battery state of charge and energy exchange is interdependent. There must be variation in the State of Charge, which indicates that the system is optimized properly. As the scheme suggest the battery bank are the secondary source of energy, they maintain the energy balance between the intermittent source of energy and the demand variation. The above picture depicts the SoC variation for May 20th of the simulated year.

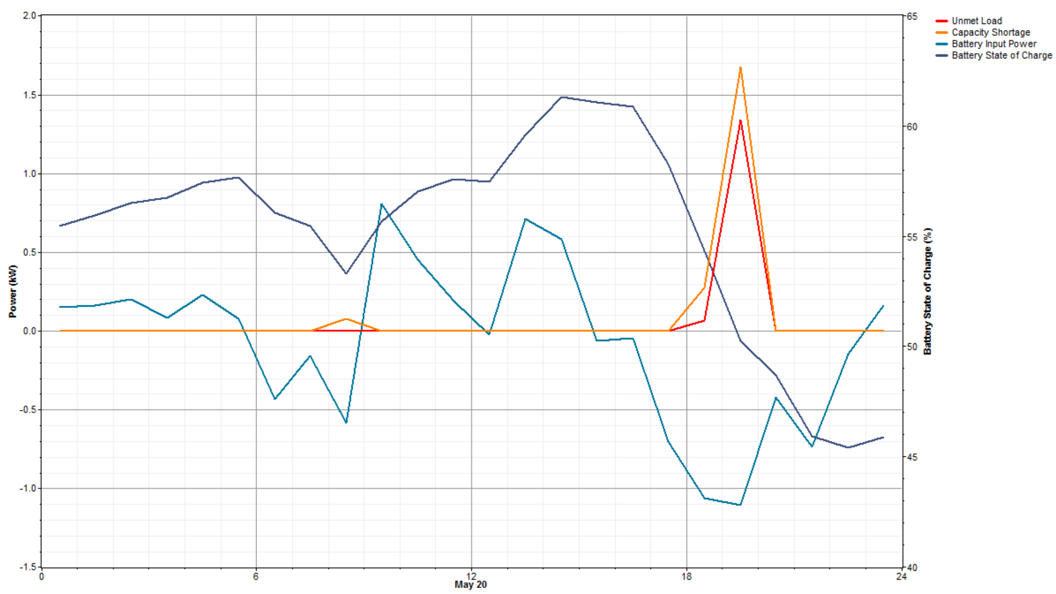

Fig. 12 Battery SoC variation

DAILY AVERAGE ENERGY PRODUCTION AND LOAD DEMAND

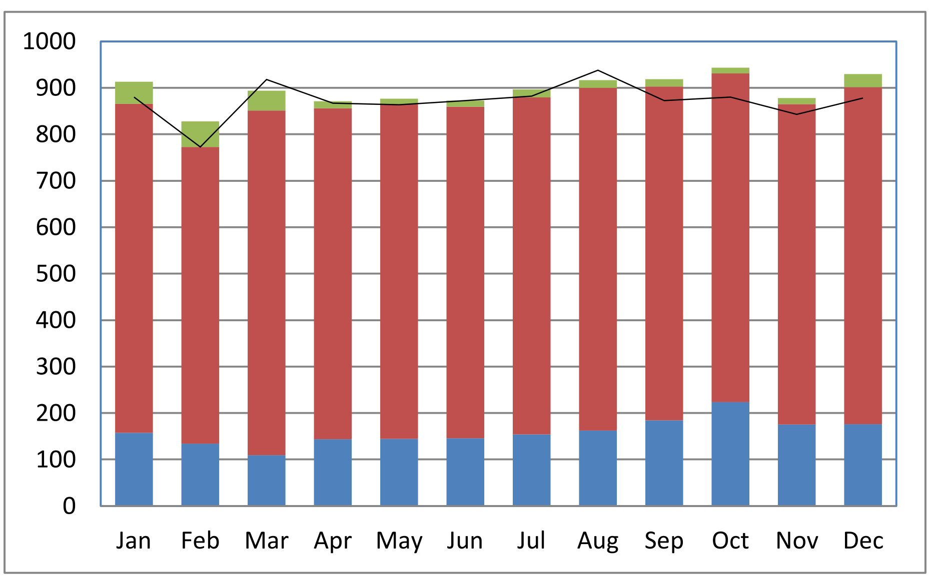

Fig. 13 Daily average energy production and load demand

The proposed scheme aims to serve the community load including 10 houses. The system has three main energy producers, backup batteries and energy storage. The production of solar PV is shown by the blue bar, the red bar representing the energy generated by the biogas equipment and the green bar representing the energy generated by the wind turbine. The main energy produced in the system is biogas, followed by solar photovoltaic and wind turbines. The average load is shown on the black line. This figure shows that this scheme is viable as it can do the maximum load part. The generation of electricity from a discontinuous source is essentially complementary, as can be seen in the figure.

RENEWABLE PENETRATION LEVEL

The novelty of the proposed model is that the penetration level of renewable energy has been achieved. In the proposed model, energy is generated through the use of photovoltaic solar cells, wind turbines and biogas generators, and all energy sources are renewable in nature. The proposed model can achieve about 100% renewable energy production if you ignore energy consumption during the production of model components and other accessories.

HOURLY ENERGY BALANCE OF THE PROPOSED SYSTEM

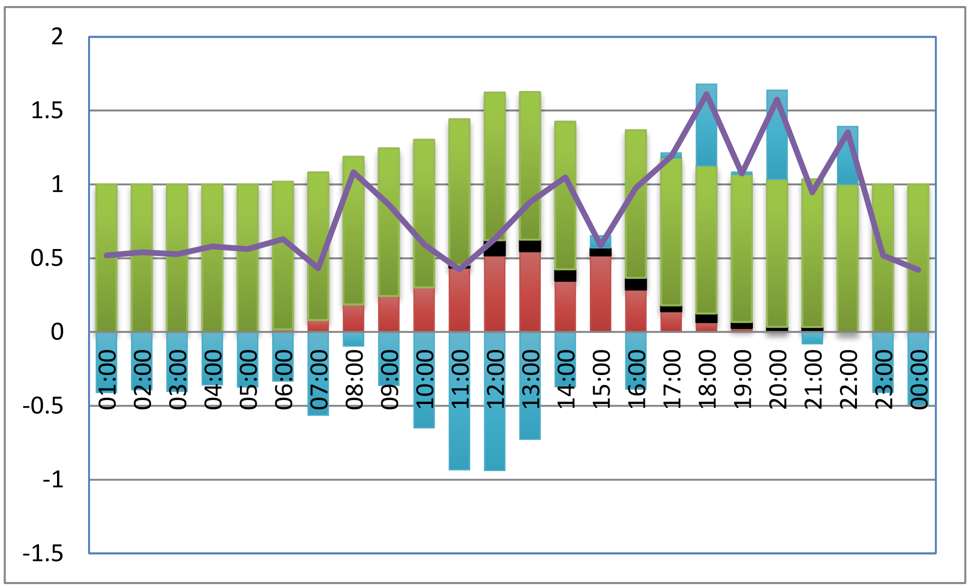

Fig. 14 Hourly energy balance

The hourly energy balance is shown in the figure below. The typical date for such an observation is July 2nd of the simulation year. The blue bar represents the energy exchange of the battery, below 0 indicates discharge and above 0 indicates battery charge. The green bar represents the biogas generator's energy output per hour. The black bar represents the wind turbine output power, and the solar output is represented by the light red bar. The diagram observes that on the evening of July 2nd, power generation from an intermittent source completely stopped the generator at full capacity, the battery began to discharge, but part of the load remained unused. This unattended load for the entire system is close to 8%. Except the load is served efficiently throughout the day. Which describes the technical capabilities of the proposed model.

SENSITIVITY ANALYSIS

Sensitivity analysis of any system is done to protect the system from market volatility. Global markets change daily. Inflation and other regulatory factors play an important role in changing the price levels of the various components used in the proposed plan. However, the main equipment used in the system is decreasing day by day.

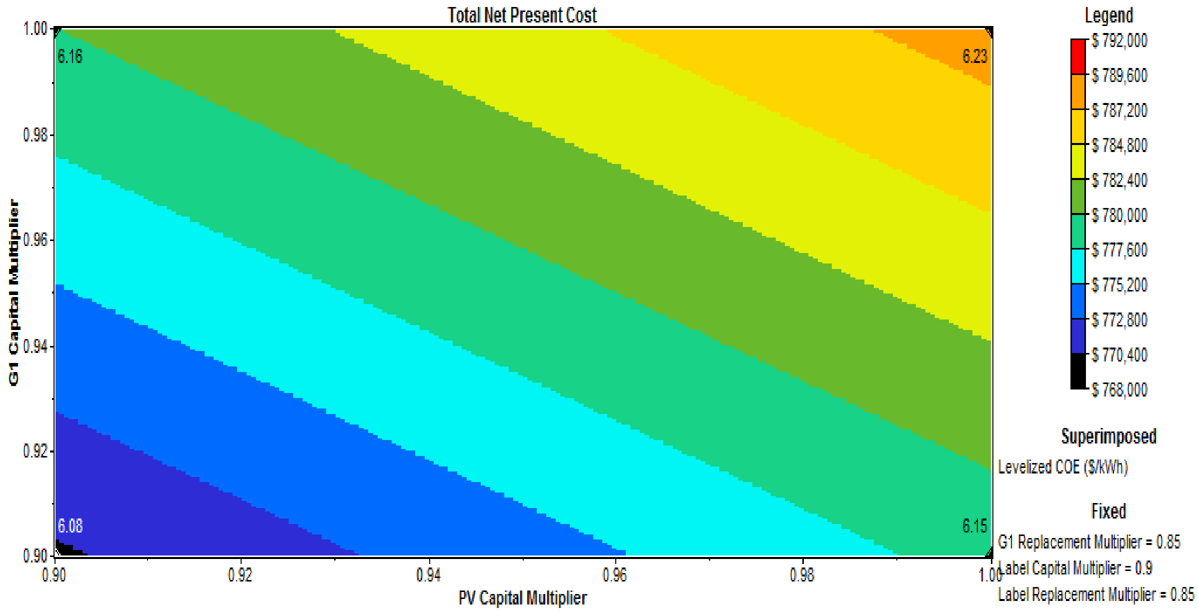

Fig. 15 Surface plot of electricity charge

In order to simulate the declining cost for the long term analysis; a 10% reduction in capital cost PV, wind turbine, biogas generator, battery and converter and Converter , and 15% reduction in replacement cost of wind turbine, biogas generator, battery and converter has been incorporated in the estimation. When merely the PV cost is reduced by the by 10%, the total COE and NPC are reduced by 1.56% and 1.77% respectively. When the biogas cost reduced by above mentioned rate, he LCoE and NPC reduced by 6.49% and 6.65% respectively. The event where wind turbine cost slashed by the above rate, the LCoE and NPC decreased by 1.57% and 1.59% respectively. If the battery and inverter simultaneously reduced by the rate mentioned above then the levilised cost of energy and net present cost are reduced by 0.55% and 0.53% respectively. If all the component cost reduced simultaneously the software calculates the cost of energy will be reduced by 10.45% and the NPC reduced by 10.53%. In all these supposition, operating cost is found to be decreased a bit with renewable fraction and capacity shortage of 1.00 and 0.08 respectively.

ECONOMIC ANALYSIS

The first figure shows the optimized biogas-wind-PV integration system produced in the HOMER software. Each column in the table corresponds to a logical model configuration. The first 5 sections show the icon, the next 5 show the number or size of each part, the next 8 sections show the main breeding results, e.g. Initial Capital Cost of the model, Cost operating cost, Net Current Cost, Adjusted COE Cost, Renewable Energy Rate and Shortage Capacity, Biomass and Label. The ideal arrangement is the one with the minimum NPC containing 1 kWP PV, 1 kW wind generator, 1 kW biomass generator, 4 S4KS2P batteries for energy storage and a 1 kW converter. Basic cost of capital is 2,66,900 INR, operating cost is 46,551 INR/year, absolute NPC is 8,61,978 INR. The observed COE is 6.81/kWh and the regeneration rate is 100%.

PV (kW)	G1	Label (kW)	S4KS25P	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage	Biomass (t)	Label (hrs)
1	1	1	4	1	$ 266,900	46,551	$ 861,978	6.810	1.00	0.08	91	8,566
1	1	1	4	2	$ 273,200	47,033	$ 874,445	6.921	1.00	0.08	91	8,566
2	1	1	4	1	$ 349,900	42,671	$ 895,383	6.895	1.00	0.05	77	7,766
1	1	1	4	4	$ 285,800	47,788	$ 896,692	7.128	1.00	0.08	91	8,523
2	1	1	2	1	$ 338,600	44,212	$ 903,778	7.059	1.00	0.07	77	8,380
1	1	1	4	5	$ 292,100	48,270	$ 909,158	7.227	1.00	0.08	91	8,523
2	1	1	4	2	$ 356,200	43,620	$ 913,816	6.914	1.00	0.02	79	7,862
2	1	1	2	2	$ 344,900	44,521	$ 914,026	7.156	1.00	0.06	77	8,334
2	1	1	8	1	$ 372,500	43,005	$ 922,245	7.086	1.00	0.05	77	7,228
1	1	1	8	1	$ 289,500	49,761	$ 925,618	7.257	1.00	0.07	92	8,622
1	1	1	4	7	$ 304,700	49,235	$ 934,091	7.426	1.00	0.08	91	8,523

Fig. 16 Optimization result of PV-wind-biogas integrated scheme

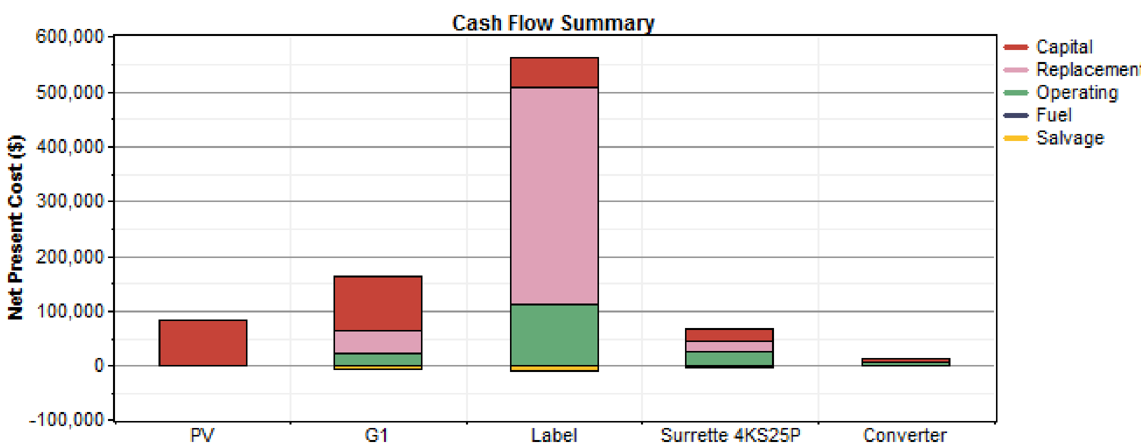

Fig. 17 Cash flow outline of the project

The net present cost of the system indicates the total value of the operating system in the current scenario. The capital is used to the maximum for biogas generators, then PV and wind turbines. Components like inverter and battery use minimal system capital.

CONCLUSION

This study examines a Solar PV-Wind-Biogas integrated model for a community load in Leh. The intermittent energy age sources are complementing each other. The model suggests a perfect balance between intermittent and consistent energy sources. It is assumed that by incorporating such a plan, the power production of the system will improve, the capacity shortfall will be bounded only by 8%, which increases system dependability, and the levilised cost of energy is 6.8 INR/kWh. The project was determined to be practicable and economically viable.

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