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Design and Optimization of Hybrid System for a Rural Based Light Industry and Domestic Load

Umar Majeed Vachkoo[1], Er Krishna Tomar[2], and Dr Satish Saini[3]

[1] M.Tech. Scholar, Department of Electrical Engineering, RIMT University, Mandi Gobindgarh Punjab, India
[2] Assistant Professor, Department of Electrical Engineering, RIMT University, Mandi Gobindgarh Punjab, India
[3] Professor and Head, Department of Electrical Engineering, RIMT University, Mandi Gobindgarh Punjab, India

Correspondence should be addressed to Umar Majeed Vachkoo; dreamkahh@gmail.com

ABSTRACT - The most popular kind of energy is electrical energy. Large power plants often create it, and the national grid then distributes it to other areas. It is obvious that India's supply of electrical energy is inadequate because of some challenging geographic features like terrain, mountains, and flood plains. Additionally, power is typically of poor quality, and outages happen frequently. Maintaining the household and light industrial load in this situation is challenging. In this study, wind energy is integrated with solar photovoltaic (PV) technology. Due to the intermittent nature of both sources, a battery bank with sufficient capacity has been installed to ensure supply continuity. Simulated in standalone mode is the system. The plan looks at various pairings, assesses cost effectiveness, and studies pollutant emission reduction. The plan attempts to recommend the ideal size of the solar PV-wind integration and the system's BoS, which will be able to deliver appropriate power quality with improved reliability and a minimal levied cost of energy.

KEYWORDS- Hybrid System, Domestic Load, Solar Wind, Renewable

I. INTRODUCTION

Nowadays, almost all aspects of human life are reliant on energy in one way or another. Energy is a "system's" capacity to perform labour [1]. A crucial component of human life is energy. For modern society to remain viable, there must be a reliable, ample, and accessible supply of energy. Worldwide, the need for energy is rising quickly, and this trend is anticipated to continue in the future [2]. Fossil fuels, nuclear power, and renewable energy are the three main types of electricity generation now in use around the world. Wood, coal, and oil, which are fossil fuels in their raw form, have historically been widely used as an energy source. Due to a variety of factors, nuclear power is not available to the great majority of people in the globe and has only found use in developed nations [3].

Different types of sources can produce or, more importantly, transform electrical energy. The sources include tidal, hydro, coal and diesel, nuclear, solar, wind, and geothermal energy. These energy sources can be broadly divided into non-conventional or renewable and conventional or non-renewable energy sources. Because they transform heat into electric energy, the steam power plant, diesel power plant, gas turbine power plant, and nuclear power plant are referred to as thermal power plants [4Humanity has easy access to renewable energy sources all throughout

the planet. Natural sources of renewable energy are not only numerous but also abundant. 13.5 percent of the world's energy demand is currently satisfied by the renewable energy sector. However, the variable output and time-dependent nature of renewable energy present a problem for its use. Flexible demand management [5-7] and smart energy management [8,9] may be helpful, but they are insufficient to maintain the equilibrium between electricity output and demand. In this context, energy storage technology may offer a practical way to solve the intermittent nature of renewable energy production [10]. When production is higher than demand, it stores the excess energy and enables for the dispatch of the stored energy when the opposite is true.

However, the generated electricity must be stored to enable the dispatch of the energy on demand in order for the intermittent solar energy to become totally reliable as a means of power supply for the base load and for monitoring the demand fluctuation. Energy storage is therefore crucial for the autonomous PV power generation and appears to be the only way to address the intermittent nature of solar energy output [14].

II. REVIEW OF SOLAR PV-WIND HYBRID SYSTEM

Ma et al. (2015) investigate a number of power supply choices, including diesel power generation and renewable energy, while taking into account one distant village. An ideal configuration for an autonomous system was discovered using a techno-economic study and a thorough hourly simulation. The effectiveness of the power supply, life cycle costs, payback periods, and greenhouse gas emissions were assessed along with the results. We also looked at how load variation affected system configuration and cost. The hybrid solar-wind-diesel-battery system could offer the best techno-economic performance, according to the feasibility study, which also discusses the possible scenario. The dispatch strategy is also shown in the paper. Additionally, take a look at a reliable power supply choice [11].

The levelized cost of electricity (LCOE) of solar photovoltaic (solar PV) and micro hydro powered village grids is calculated by Bulm et al. (2013) and contrasted with the traditional diesel option. Investigate various system designs for solar photovoltaics, such as a reduced supply contingency and a hybridization strategy. Lastly, determine the possible savings and expenses of CO2 emission reduction. When implemented with a reduced supply contingency and the remoteness of the village grid, solar PV powered solutions become more competitive. Micro hydro powered village grid systems are found to offer substantial potential to cut emissions while having negative abatement costs [12].

The design, operation, and control requirements of standalone PV solar-wind hybrid energy systems with a traditional backup source, such as diesel or the grid, are reviewed by Nema et al. (2009). The future advancements that could improve the economic allure of such systems and the user's acceptance of them are also highlighted in this paper [13].

Ahok (2007) covers the various hybrid energy system components and creates a generic model to determine the best possible combination of energy sources for a typical rural community while minimising life cycle costs. The created model will aid in determining the operational options and the hardware sizing for hybrid energy systems. According to the study, micro-hydro-wind systems are the best setup for electrifying rural villages in India's Western Ghats (Kerala) [14].

In order to help readers choose between solar home and microgrid, Kandpal et al. (2010) present a techno-economic comparison of the two options based on annualised life cycle costs (ALCC) for the same type of loads and load patterns for varying numbers of households as well as varying length and costs of distribution network. According to the study, installing a microgrid is often a more cost-effective alternative for a town with a flat geographic landscape and more than 500 densely populated homes that utilise 3–4 low power appliances (such 9W CFLs) for an average of 4 hours per day. The study evaluates the two solutions' viability from the viewpoints of the user, an energy service provider, and society [15].

Domenech et al(2014) .'s goal is to describe the technical design of the electrification system of the community of Alto Peru (in the region of Cajamarca, Peru), where the appropriate technology was used at each area in accordance with the socioeconomic needs of the local population and the micro-scale resource evaluation. Four technologies in particular were put into practise: wind microgrids in highlands, a micro-hydro power plant near a waterfall, a PV microgrid in a collection of wind-sheltered spots, and individual PV systems in dispersed locations with limited wind potential. In addition to 58 homes, a health centre, a school, a church, two restaurants, and two shops, this project also provided power [16].

In their study on solar energy, Akikur et al. (2013) describe stand-alone and hybrid power generation systems that can be utilised to electrify remote regions. The standalone solar-PV system created here is designed to power a single home or a small town. It also serves as a mini-grid, producing electricity in locations where year-round access to sufficient solar radiation is possible. However, a hybrid solar-PV system is the most effective method of electrification in locations where solar radiation levels are erratic, which is common around the world. A few comparative case studies,

project examples, and demonstrations of standalone and hybrid solar systems used in various parts of the world are also included in this article [17].

According to Liu et al. (2013), the study investigates the main barriers and crucial elements that influence the use of renewable energy in Taiwanese buildings. The study identified the major influences and key factors, and it made recommendations for future energy development strategies to enhance the quality and quantity of renewable energy applications and the competitiveness of national energy through the evaluation decision-making system model and expert decision-making groups providing evaluation values and feedback. In addition to offering references to pertinent environmental energy systems for deployment and technological research and development, this website also gives emerging and impoverished countries access to assessments and future projections of solar energy technologies [18].

The performance of group off-grid photovoltaic (PV) systems in rural areas is analysed by Dáz et al. in 2011. The study is based on the field functioning of twelve community PV installations that provide electricity to remote settlements in Argentina's Jujuy province. While seven of them also rely on diesel groups, five of them use PV generators as their only power source. Analysis is done on fuel usage, energy production, and load demand evolution. Additionally, energy generation methods (PV/diesel) are also covered [19].

Ma et al. (2013) look into the outcomes of an actual remote solar PV project on a Hong Kong island. Originally powered by diesel generators, the new solar energy system on this island has drastically decreased fuel costs while reducing environmental pollutants. The energy performance of the PV array, inverters, battery bank, and full PV system was examined in terms of daily energy balance, normalised performance parameters, and overall system energy utilisation ratio. Operating data for the entire on-site system was gathered for an entire year. The outcomes of the system monitoring and assessment allow for a thorough examination of the system's operational performance in relation to the technical difficulties, which is also covered [20].

A hybrid solar and grid-connected electricity system for houses and buildings is suggested by Ali et al. (2010). As an alternative to the already prevalent method of utilising solid-state inverters to convert the solar DC supply into AC, appropriate for running ordinary electrical appliances, a novel idea of combining a DC motor and synchronous generator as an electromechanical inverter is offered. A 2kW hybrid system is suggested with the quantity of solar panels, synchronising control, and system block concept [21].

Zhiyuan (2012) examines the autonomous wind-solar hybrid power system's operational traits with the aim of enhancing system dependability and energy conversion efficiency. The functioning of power producing units is regulated using a proposed coordinated control mechanism based on the condition of the energy storage unit. Due to the independent wind-solar hybrid power system's coexistence of continuous and discrete system features, hybrid simulation studies are conducted. The findings show that the system can control energy flow reasonably under various load and weather situations. As a result, the suggested coordinated control strategy can guarantee the independent, optimal operation of a wind-solar hybrid power system [22].

The research on unit sizing, optimization, energy management, and modelling of the hybrid renewable energy system components is reviewed by Bajpai et al. (2012). Research on power conditioning units (MPPT converters, Buck/Boost converters, Battery chargers), backup energy systems (Fuel Cell, Battery, Ultra-capacitor, and Diesel Generator), modelling of hybrid energy resources (PV systems), and methods for managing energy flow have all made significant strides. An effort has been made to offer a thorough analysis of the research that has been done in this field over the past ten years in this publication [23].

On the basis of a case study, Pradhan et al. (2012) examine the suitability of a hybrid solar and wind power system. For hybrid stand-alone applications in off-grid rural locations, hybrid solar and wind energy appear to be viable alternatives to deliver dependable power supply with increased system efficiency. The approach for examining the dependability of a small freestanding hybrid solar/wind power system is presented in this study (HSWPS). The HSWPS reliability indices will be implemented using the analytical reliability evaluation technique [24].

By using an Integrated Renewable Energy Optimization Model, Kanase-Patil et al. (2011) demonstrate the electrification of dense forest areas in the Indian state of Uttarakhand (IREOM). To satisfy the energy needs of villages, the IREOM uses locally accessible renewable energy sources such Micro-Hydropower (MHP), biomass, biogas, wind, and solar photovoltaic (SPV) systems. In order to determine the best combination of energy subsystems for the chosen research region and to reduce the cost of energy (COE) generation for the given reliability values, the article contains the selection of components, sizing, and construction of a general model. Four different seasonal load profiles have been taken into consideration while sizing various renewable energy system components. For the purpose of choosing the best option for year-round application, the two reliability values are taken into account. The model created for this aim has been shown to be very helpful in maximising the sizes of commercially available renewable energy systems. The proposed concept completely forgoes the usage of traditional energy systems and relies solely on renewable energy sources [25]

III. METHODOLOGY USED IN THE STUDY

A. PV Performance Assessment

A big photovoltaic (PV) system's energy yield over a long period of time should be documented for a number of reasons, including to analyse the system's health, validate a performance model that will be used to design a new system, and quantify a performance guarantee. Although it might seem simple to assess this performance indicator, there are a lot of intricacies related to weather variability and inaccurate data collecting that make the decision and data analysis difficult. Although there is currently no standard to help with this process, performance assessments are most beneficial when they are conducted with a very low level of uncertainty and when the subtleties are methodically handled [26].

B. Wind Energy Assessment

According to physics, the energy (per unit time) of wind flowing at a speed v (m/s) through an intercepting area A (m2) is proportional to

However, the actual link between the wind speed and the power produced by the entire wind farm may be more complicated. This idea is demonstrated in Fig. 1. The so-called machine power curve of a certain wind turbine within a wind tunnel is shown in Fig. 1 as it may look, for example, in the information provided by its manufacturer. It represents the deterministic output power as a function of the input wind velocity. We can observe from this machine power curve that the wind turbine does not generate electricity below a certain minimum wind speed, known as the connection speed. The power increases as the wind speed does after this connection speed. Similar to the rising pattern illustrated in Fig. 1, the contour of this expanding portion of the power curve is dependent on the specific technology used in the wind turbine. The electricity meets the wind turbine's rated capacity when the speed increases and reaches the so-called nominal speed. The output power is maintained constant for a certain range of wind speed after the nominal speed. As the wind speed surpasses the nominal speed, various technical solutions are also available to maintain this constant level. In order to prevent damage from extreme wind, the wind turbine is finally disconnected when the wind speed exceeds the so-called disconnection speed.

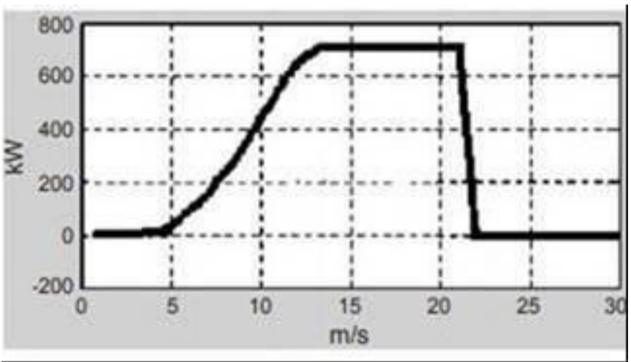

Figure 1: A typical machine power curve in a wind tunnel

C. Simulation Methodology

In this work, modelling and simulation are carried out using the Hybrid Optimization Model for Electric Renewable (HOMER) software, a renewable energy-based system optimization tool developed by the National Renewable Energy Laboratory (NREL) of the United States (US). This micro power optimization software has been widely used in numerous previous studies on hybrid energy systems in other nations, and it is recommended here as well to simulate a workable hybrid system for the site. This adaptable tool simulates a combination of fossil fuels and renewable energy sources to identify the most economically advantageous configuration for each system. Electric load (primary energy demand), renewable resources (solar radiation), hydro resources, component technical details/costs, kind of dispatch strategy, etc. are some of the input data that must be provided in HOMER [27].

The proposed system is built to handle a peak load of 47 kW and a daily load of 247 kWh. This, however, shows the typical load requirement. In addition, the upcoming increase in equipment will result in a spike in power demand. The system is primarily created to handle residential load or domestic demand. Additionally, it is clear that evening hours are when the load is at its peak demand. The scheme solely generates energy during the day in order to support load at night through battery arrangement. Because of this, in this study the daily base load to be satisfied by the suggested method is assumed to be 247 kWh/day, and then a load profile that is both plausible and random is created using HOMER software. The seasonal variation of load is also not taken into account for simplicity. For the simulated year, the proposed scheme's load is assumed to be constant throughout all the months.

D. Solar Energy Resource

The use of solar energy is crucial to the suggested plan. The amount of power produced by the PV array is growing as technology advances. The PV array's ability to produce power is influenced by the environment in which it is put. India's average daily solar radiation variation is reported to be between 4-6 kWh/m2. The investigation is carried out at latitude 34.15 degrees and longitude 77.57 degrees. And with a clearness index of 0.702 and a monthly average daily solar radiation of 5.61 kWh/m2/day at the proposed site, the PV array's installed power is 60 kWP.

IV. MODELING OF PV-WIND HYBRID SYSTEM

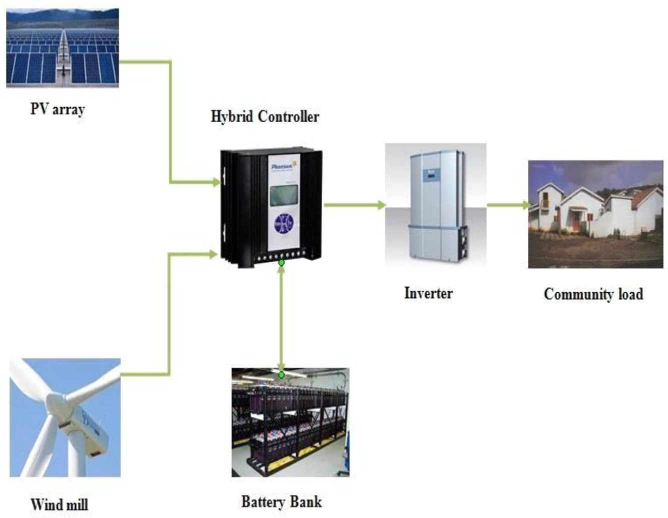

Figure 2: PV-wind hybrid system

The hypothetical system under consideration is outfitted with a power source (a PV array and battery), a load, and a control station. It is be lieved that the system is being used in stand-alone mode. The study was designed with Jammu's agricultural sector in mind. The PV array, wind turbine, battery, balance of system components (inverter, converter, and charge controller), and these are the main parts of the system (fig. 2).

A. Load Profile

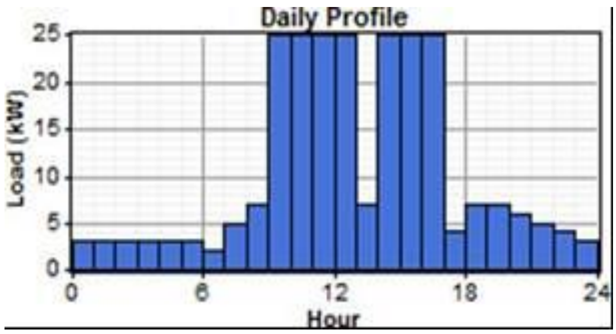

Figure 3: Hourly load

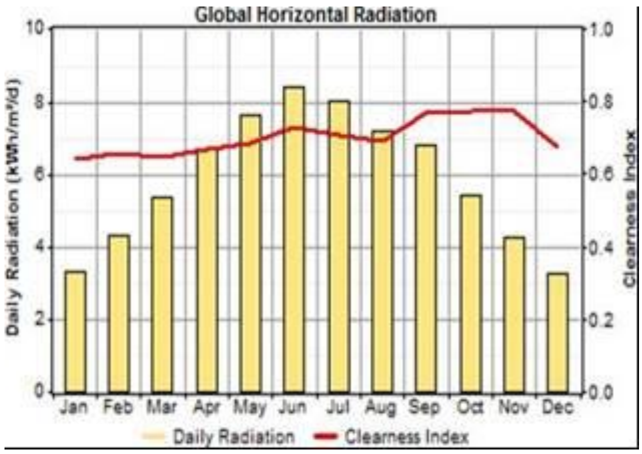

Figure 4: Solar energy resources

In this proposed scheme the capital cost for the 60 kWP PV array is taken as INR 48,60,000 and replacement cost and O&M cost are considered as negligible value.

B. Wind Resource

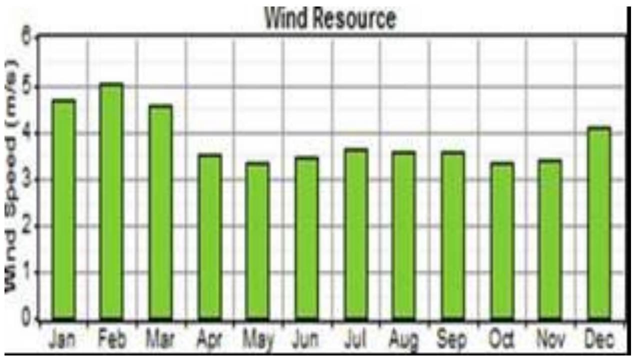

Figure 5: Wind energy resources

The proposed model(fig. 5) includes a wind resource to take advantage of the wind's energy.

The windmill is only used in this study for experimental purposes, hence the size of the turbine is limited to 2kW. The SW AIRX model is used for this. The estimated life of a wind turbine is 15 years. At the proposed site, the scaled annual average wind speed is 3.82 m/s. O&M costs of INR 20,000 and capital costs of INR 2,000 are taken into account.

C. Battery

The only source of energy production in the suggested plan is a solar PV array. The weather affects the PV array's ability to produce power. Additionally, a source must be set up to meet the need for the load during the night. The PV array is not capable of generating varying amounts of power. Improve the quality of power battery is integrated with the PV system to reduce the intermittent features. The Surrette 4KS25P battery is employed in 60 units for the modelling of the scheme. The capital cost of the battery sub-system is assumed to be INR 3,42,000 for the proposed plan, with an O&M cost of INR 34200 per year.

Converter

A component that enables the PV-generated electricity to be applied to the load properly is required by the proposed plan. This component is frequently referred to as the "balance of system," or BOS.

All elements of a solar system, outside the photovoltaic panels, are referred to as the balance of the system (BOS) [3]. This includes battery banks, chargers, mounting hardware, switches, one or more solar inverters, wiring, and battery systems. BOS is used to securely convey the electricity to the intended load, to condition the electricity for use, and/or to store the electricity for later use. Batteries, a charge controller, equipment for power conditioning, safety devices, metres, and instrumentation are examples of typical balance-of-system components for a stand-alone system. Solar inverter and a standalone charge controller, which are both combined to form a controller, are crucial parts of BOS for the study. The variable direct current (DC) output of a photovoltaic (PV) solar panel is converted by a solar inverter, converter, or PV inverter into a utility frequency alternating current (AC), which can then be used by a local, off-grid electrical network or supplied into a commercial electrical grid. It is a crucial component of a photovoltaic system's balance of system (BOS) that enables the use of standard AC-powered equipment. Maximum power point tracking and anti-islanding prevention are only two of the unique features that solar power converters have developed specifically for use with photovoltaic arrays. The load is considered to be AC in the proposed study, while the solar PV system produces DC electricity. Therefore, inverter or solar inverter is employed in this design instead of converter. The converter's size is 30 kW, and its specifications call for a 15-year lifespan and a 90 percent efficiency. The capital cost and annual O&M costs for the proposed plan are assumed to be INR 2,03,280 and 20328, respectively.

V. ECONOMIC ANALYSIS

The hybrid system's overall optimization result, which was produced using the HOMER software, is displayed in Table 1. The table's rows each reflect a workable system configurationThe first three columns display an icon, the following three indicate the number or size of each component, and the following six columns display important simulation results, including the system's capital cost, operating cost, Net present cost, levelized cost of COE, share of renewable energy, and capacity shortage. The configuration with the lowest NPC is one that includes 60 kWP PV, a 2 kWP windmill from SW AIR X, 60 S4KS25P batteries, and a 30 kW converter. The COE is determined to be 6.367/kWh with a 100% renewable share and a 10% capacity shortfall.

Table 1: Optimization result of PV standalone system

				PV (kW)	AIR	S4KS25P	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage
				60	2	60	30	$ 5,605,280	99,431	$ 6,876,337	6.367	1.00	0.10
				60	2	60	30	$ 5,605,280	98,351	$ 6,862,530	6.354	1.00	0.10
				60	2	60	30	$ 5,605,280	97,270	$ 6,848,724	6.342	1.00	0.10
				60	2	60	30	$ 5,584,952	99,431	$ 6,856,009	6.348	1.00	0.10
				60	2	60	30	$ 5,584,952	98,351	$ 6,842,202	6.335	1.00	0.10
				60	2	60	30	$ 5,584,952	97,270	$ 6,828,396	6.323	1.00	0.10
				60	2	60	30	$ 5,564,624	99,431	$ 6,835,681	6.329	1.00	0.10
				60	2	60	30	$ 5,564,624	98,351	$ 6,821,874	6.317	1.00	0.10
				60	2	60	30	$ 5,564,624	97,270	$ 6,808,068	6.304	1.00	0.10
				60	2	60	30	$ 5,605,280	96,593	$ 6,840,060	6.334	1.00	0.10
				60	2	60	30	$ 5,605,280	95,513	$ 6,826,254	6.321	1.00	0.10
				60	2	60	30	$ 5,605,280	94,433	$ 6,812,447	6.308	1.00	0.10
				60	2	60	30	$ 5,584,952	96,593	$ 6,819,732	6.315	1.00	0.10
				60	2	60	30	$ 5,584,952	95,513	$ 6,805,925	6.302	1.00	0.10
				60	2	60	30	$ 5,584,952	94,433	$ 6,792,119	6.289	1.00	0.10
				60	2	60	30	$ 5,564,624	96,593	$ 6,799,404	6.296	1.00	0.10
				60	2	60	30	$ 5,564,624	95,513	$ 6,785,597	6.283	1.00	0.10
				60	2	60	30	$ 5,564,624	94,433	$ 6,771,790	6.270	1.00	0.10

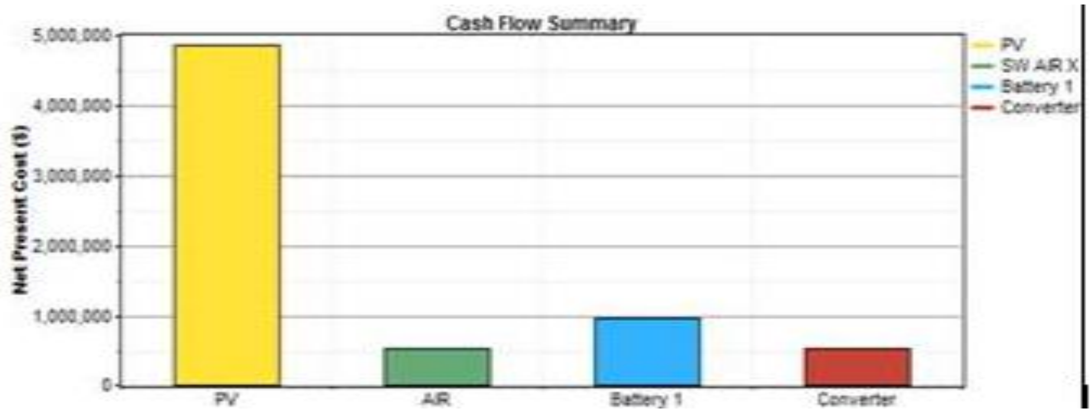

Figure 6: Cash flow outline of the project

It does a cash flow analysis, as indicated in the figure 6, to ascertain NPC. According to the system's components that have been chosen, it displays the cash flow outline. PV splits the highest capital expense. The best optimal model's NPC summary is shown in the below table 2.

Table 2: Net present cost

Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
PV	4,860,000	0	0	0	0	4,860,000
SW AIR X	200,000	83,453	255,667	0	-15,533	523,587
Battery 1	342,000	254,430	437,191	0	-73,045	960,576
Converter	203,280	84,822	259,860	0	-15,788	532,174
System	5,605,280	422,705	952,718	0	-104,366	6,876,337

The below fig. 7 shows the annual cash flow over the course of the system's existence. Each bar on the graph indicates the total amount of money that came in or went out over the course of a certain year. The capital cost of the system is displayed in the first bar for year zero. An outflow (expenditure) related to equipment replacement or O&M is represented as a negative figure. Possible replacement of the wind turbine in year 15, the converter in year 15, and the battery in years 12 and 24. A positive figure indicates an inflow, which could be income from the equipment's salvage value at the end of the project's lifespan.

Table 3: Annualized cost

Component	Capital ($/yr)	Replacement ($/yr	O&M ($/yr)	Fuel ($/yr)	Salvage ($/yr)	Total ($/yr)
PV	380,182	0	0	0	0	380,182
SW AIR X	15,645	6,528	20,000	0	-1,215	40,958
Battery 1	26,754	19,903	34,200	0	-5,714	75,143
Converter	15,902	6,635	20,328	0	-1,235	41,630
System	438,483	33,067	74,528	0	-8,164	537,913

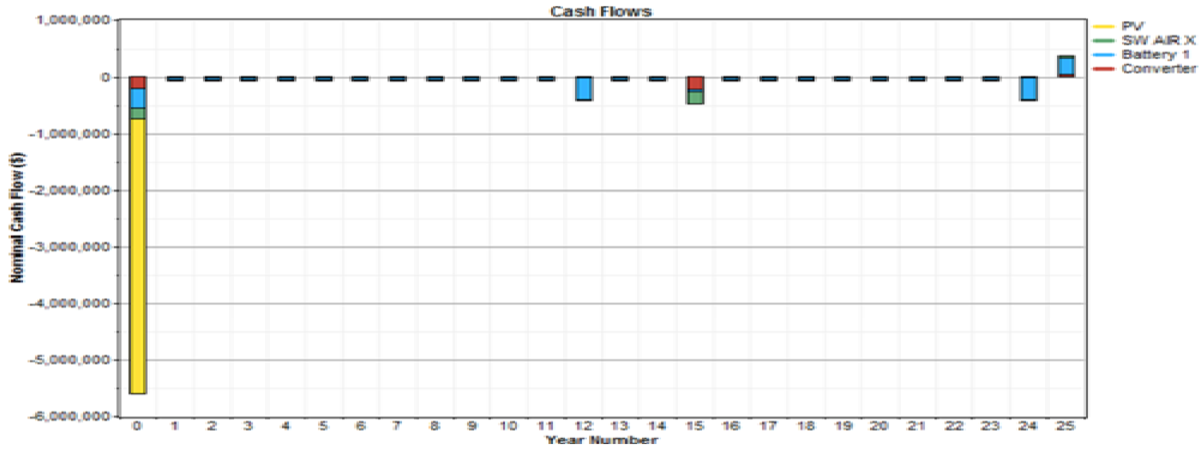

Figure 7: Cash flow information of the scheme

VI. PERFORMANCE SUMMARY OF DIFFERENT SYSTEM COMPONENTS

Table 4: Summary of Different System Components

Parameters	Value	Unit
PV array		
Rated capacity	60	kW
Mean output	12.9	kW
Mean output	310	kWh/d
Capacity factor	21.5	%
Total production	113,119	kWh/year
Minimum output	0	kW
Maximum output	56.9	kW
PV penetration	125	%
Hours of operation	4,382	hour/year
Levelized cost	3.36	$/kWh
IAR SWX		
Total rated capacity	0.800	kW
Mean output	0.02	kW
Capacity factor	2.07	%
Total production	145	kWh/yr
Minimum output	0.00	kW
Maximum output	0.21	kW
Wind penetration	0.161	%
Hours of operation	4,350	Hr
Levilized cost	283	$/kWh
Battery		
Nominal capacity	456	kWh

VII. CONCLUSION

The hybrid PV-wind system is looked at in this study. The outcomes look promising. The study's findings include the following: the integration of a battery increases the system's power output; the schemes used in the study are complementary in nature; there is a capacity shortage of 0.10 percent, which also improves the scheme's dependability; the levied cost of energy is reduced from an average of 10 INR/kWh to 6.367 INR/kWh; and the proposed scheme also emits very little waste, making it environmentally friendly.

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