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Techno-Economic Analysis of a Grid-Connected Hybrid PV/Wind Power System- Case Study at Leh Ladakh in India

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ABSTRACT
The national grid is able to provide round the clock energy supply. Some region of India owing their geographical not able to get continuous power supply from the grid, one such location is Leh. The power delivered in that region is of very low quality, having frequent outage and the reliability of the supply becomes a challenge. During harsh environment the supply and reliability affected greatly due to the restricted movement of man and material. On the other hand, renewable energy supply being located on the site of installation can be able to eliminate such challenges. Hybrid combination of PV and Wind along with some storage facilities can mitigate the challenges. The storage battery increases the project cost and also releases pollutants during their operation. So the study uses the existing national grid to exchange the energy, the combination of PV-wind with the national grid. The study finds out the optimal size of such combination, focusing on the reliability and cost effective energy supply.

Keywords
Hybrid, Technical, Economic, Photovoltaic, Wind, Net Present Cost

1. INTRODUCTION
Energy is a vital element in human life. A secure, sufficient and accessible supply of energy is very crucial for the sustainability of modern societies. The demand for the provision of energy is increasing rapidly worldwide and the trend is likely to continue in future. The economic performance of a country depends on its available energy resources. Many researchers have concluded positive prospects of renewable energy in their respective countries. In the literature, the hybrid systems are described in many studies both experimentally and numerically such as PV/Wind/Battery[1-4], PV/Wind only [5-9] PV/Wind/micro turbine/battery [10] and PV/Wind/Fuel cell [11,12]. The selection process for hybrid power sources at a given site is dependent on a combination of many factors, including the load demand, site topography, seasonal availability of energy sources, cost of energy storage and delivery, seasonal energy requirements, etc. [13]. Diemuodeke et al. indicated the utilization of PV Battery- Diesel generators in Nigeria which would in turn decrease dependency on diesel generators [14]. Similarly, Sayedus Salehin et al. showed the benefits of using hybrid PV-diesel energy system in Char Parbotipur, Bangladesh [15]. Hussein M. Al-Masri and Mehrdad Ehsani (2019) investigated the feasibility of retrofitting on grid systems with wind and solar generators. They selected the city of Ibrahimiyyah in Jordan for its high solar radiation and wind speed [16]. Considering the global energy production, it is dominated by the conventional sources such as diesel based thermal power plant, coal based thermal power plant, nuclear-based thermal power plant and hydroelectric power plant. However, renewable energy sector is now growing faster than the growth in overall energy market. Renewable energy resources are easily accessible to mankind around the world. Renewable energy is not only available in a wide range, but are also abundant in nature. Some long-term scenarios postulate a rapidly increasing share of renewable technologies (made up of solar, wind, geothermal, modern biomass, as well as the more traditional source i.e. hydro). Under these scenarios, renewable could meet up to 50% of the total energy demand by mid-21st century with appropriate policies and new technology developments [17]. In this back drop the current work aim to investigate the PV-Wind-grid hybrid option to enhance the reliability of the supply by removing the dependency upon the grid power supply. Hybrid energy system is an excellent solution for electrification of remote areas where the due to geographical challenges the grid extension cannot ensure the reliability of supply. Such system incorporates a combination of one or several renewable energy sources such as solar photovoltaic, wind energy, micro-hydro and may be conventional generators or the oldest, mature and traditional technology battery bank for backup. But both the generators and batteries emits pollutants at the site of installation and disturbs the ecological settings, so for ecological sensitive zones these options are not feasible. This proposed model consists of hybrid energy system as PV-wind with grid.

2. METHODOLOGY
In this research hybrid system has been selected by combining PV, wind and grid. The word hybrid essentially stands for a system, which is a result of combining two or more different elements. In power generation hybrid system usually combines two or more main sources of energy. Solar and wind energy vary in intensity due to the intermittent nature of renewable resources, so due to this if the system is standalone, a reliable system for backup must be available for continuity of supply. The research has been carried out using the simulation software HOMER developed by Renewable Energy Laboratories (NREL). The system has been modelled for supplying electricity to a small community which was assumed to have an annual average load demand of 127 kWh/day with a peak load of 16 kW.

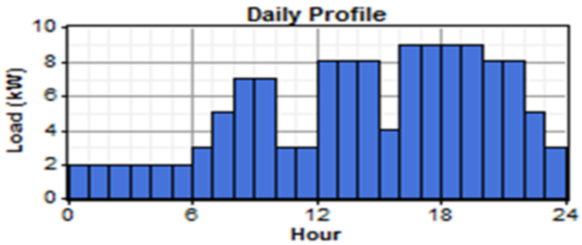

Figure 1: Hourly load

Figure 1 represents the load profile. However, this represents the average load demand. Besides, the power demand will rise due to the increasing number of equipment in near future. The system is mainly design to cater the domestic demand or household load. It can be also seen that the peak demand of the load is occurring in evening time. The power production of the scheme is only in day time for cater load during night battery arrangement is done. Therefore, in this study the daily base load to be served by the proposed scheme is assumed as 127 kWh/day and then synthesized in HOMER software by adding randomness of day, to create a quite reasonable load profile. And for simplicity the seasonal variation of load is not considered. The load of the proposed scheme is taken as constant in all the months for the simulated year.

3. COMPONENTS

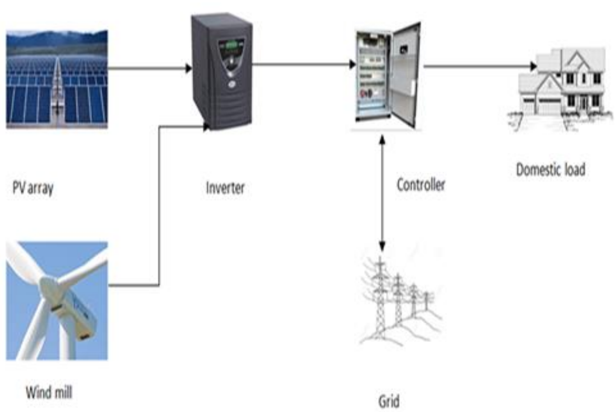

Figure 2: Components

3.1 Solar energy resource (PV Array)

For the proposed scheme solar energy plays an important role. With the advancement in technology the power production from the PV array is increasing. The power production from the PV array is dependent on the weather condition at which it is being installed. Typical variation of solar radiation in India is found to be 4-6 kWh/m2/day. The study is conducted at 34.15-degree latitude and 77.57-degree longitude. And for the proposed site monthly average daily solar radiation found to be 5.86 kWh/m2/day with clearness index of 0.702, the installed capacity of the PV array is 50 kWP. In this proposed scheme the capital cost for the 50 kWP PV array is taken as INR 40,50,000and replacement cost and O&M cost are considered as negligible value.

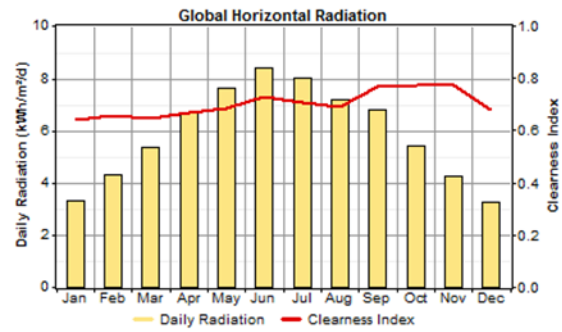

Figure 3: Solar energy resources

3.2 Wind Resource (Wind Mill)

Wind resource is included in the proposed model to harness the energy present in the wind. In this study the wind mill is kept for experimental purposes only, so the size of the turbine is restricted around 2kW, SW AIRX model is chosen for the purpose. The life span of the wind mill is taken as 15 years. The scaled annual average of wind speed is 3.817 m/s at the proposed site. The Capital cost of INR 2,00,000 and O&M of INR 20,000 is considered.

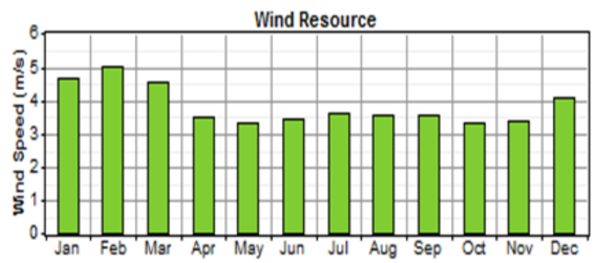

Figure 4: Wind energy resources

3.3 National Grid

For simplicity the cost of sale and cost of purchase of energy by the grid from the system only included. As the Grid was present previously so no extra cost is added. The grid purchase power from the hybrid system is INR 4.50/kWh and sold at INR 5.00/kWh. The repurchase agreement is considered here

3.4 Converter

The proposed scheme needs a subsystem that enables the PV-Wind generated electricity to be properly applied to the load. This subsystem is often called the "balance of system," or BOS. The balance of system (BOS) encompasses all components of a photovoltaic system other than the photovoltaic panels [18]. This includes wiring, switches, a mounting system, one or many solar inverters, a battery bank and battery charger. BOS is used to condition the electricity, safely transmit the electricity to the load that will use it, and/or store the electricity for future use. Typical balance-of-system equipment for a stand-alone system includes batteries, charge controller, power conditioning equipment, safety equipment, and meters and instrumentation. The essential component of BOS for the study is inverter and controller both are integrated to the grid. In the proposed study the load is assumed in AC and the power output from solar PV is DC. So for this scheme inverter or solar inverter is used instead of converter. The size of converter used is 30 kW and have the specification as life time 15 years and having efficiency of 90%. For the proposed scheme the capital cost is taken as INR 2,03,280 and O&M cost are 20,328 annually.

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4. ECONOMIC PARAMETERS

4.1 Operating Reserve

Operating reserve is surplus operating capacity that can instantly respond to a sudden increase in the electric load or a sudden decrease in the renewable power output. Operating reserve provides a safety margin that helps ensure reliable electricity supply despite variability in the electric load and the renewable power supply.

4.2 Total Net Present Cost

The total net present cost of a system is the present value of all the costs that it incurs over its lifetime, minus the present value of all the revenue that it earns over its lifetime. Costs include capital costs, replacement costs, O&M costs, fuel costs, emissions penalties, and the costs of buying power from the grid. Revenues include salvage value and grid sales revenue.

The system cost can be given by the equation

$$C_{NPC} = \frac{C_{ann,tot}}{CRF_{(i,R_{proj})}}$$

Where $C_{ann,tot}$ is the total annual cost; i is the annual real interest rate (discount rate); R_{proj} represents the project lifetime; and CRF (i, R_{proj}) is the capital recovery factor.

4.3 Capital Recovery Factor

The capital recovery factor is a ratio used to calculate the present value of an annuity (a series of equal annual cash flows). The equation for the capital recovery factor is:

$$CRF(i,N) = \frac{i(1+i)^N}{(1+i)^N - 1}$$

Where i is the annual real interest rate and N is the number of years. The real interest rate was calculated as 6% and project life of 25 years was used in this study.

4.4 Operating cost

The total operating cost is the sum of the annual operation and maintenance (O&M) costs, total fuel cost, and annualized replacement cost minus the annualized salvage value. For grid-connected systems, the operating cost includes the annualized cost of grid purchases minus grid sales.

4.5 Project life time

The project lifetime is the length of time over which the costs of the system occur. Simulation uses the project lifetime to calculate the annualized replacement cost and annualized capital cost of each component, as well as the total net present cost of the system. Its symbol is R_{Proj} and measured in year. Here the project life time is taken as 25 years.

4.6 Salvage Value

Salvage value is the value remaining in a component of the power system at the end of the project lifetime. Simulation assumes linear depreciation of components, meaning that the salvage value of a component is directly proportional to its remaining life. It also assumes that the salvage value is based on the replacement cost rather than the initial capital cost. This is expressed mathematically as:

$$s = C_{rep} . \frac{R_{rem}}{R_{comp}}$$

R_{rem}, the remaining life of the component at the end of the project lifetime, is given by:

$$R_{rem} = R_{comp} - \left(R_{proj} - R_{rep}\right)$$

R_{rep}, the replacement cost duration, is given by:

$$R_{rep} = R_{comp} . INT\left(\frac{R_{proj}}{R_{comp}}\right)$$

Where C_{rep}= replacement cost[$],$R_{comp}$= component lifetime [year] and R_{proj}= project lifetime [year]

4.7 Renewable Fraction

The renewable fraction is the portion of the system's total energy production originating from renewable power sources. Software calculates the renewable fraction by dividing the total annual renewable power production (the energy produced by the PV array, wind turbines, hydro turbine, and biogas-fueled generators) by the total energy production.

$$f_{ren} = \frac{E_{ren}}{E_{tot}}$$

Where Eren renewable electrical production in kWh and Etot is the total electrical production in Kwh.

4.8 Annual Interest Rate

The interest rate that one enters for simulation's input is the annual real interest rate (also called the *real interest rate* or just *interest rate*). It is the discount rate used to convert between one-time costs and annualized costs. It is found in the Economic Inputs window. The annual real interest rate is related to the nominal interest rate by the equation given below.

$$i = \frac{i' - f}{1 + f}$$

Where i = real interest rate, i'= nominal interest rate and f = annual inflation rate.

4.9 Levelised Cost of Energy

Software defines the levelised cost of energy (COE) as the average cost per kWh of useful electrical energy produced by the system. To calculate the COE, simulation divides the annualized cost of producing electricity (the total annualized cost minus the cost of serving the thermal load) by the total useful electric energy production. The equation for the COE is as follows:

$$COE = \frac{C_{ann,tot}}{E_{prim,AC} + E_{def}}$$

Where $C_{ann,tot}$ = the total annualized cost of energy [$/kWh], $E_{prim,AC}$= AC primary load served [kWh/year] and E_{def}= deferrable load served [kWh/year]

5. SIMULATION METHODOLOGY

Hybrid optimization model for electric renewable (HOMER) software [28], the renewable energy based system optimization tool developed by the United States (US) national renewable energy laboratory (NREL) is used in this work for modeling and simulation purpose. There exists wide use of this micro power optimization software in various preceding hybrid energy system studies in different countries and preferred here as well to simulate a feasible hybrid system for the site. It is a flexible tool that models a mix of conventional fuels and renewable energy to determine the most cost effective configuration for each system. Input information to be provided in HOMER includes: electric load (primary energy demand), renewable resources (solar radiation), hydro resources, component technical details/costs, type of dispatch strategy, etc. [19].

6. RESULTS AND DISCUSSIONS

6.1 Solar Power Output

The monthly variation of output from the PV array is shown in the below graph (Fig 5). It is seen that the power output from the PV array is adequate throughout the year and being highest in the month of April. So all through the year PV array can produced a reasonable amount of power. As the proposed site is dominated by monsoon weather so the power output from the PV array from June to August is less due to the presence of cloud. According to the climate condition the power output from the PV array is estimated as 98,968 kWh/yr.

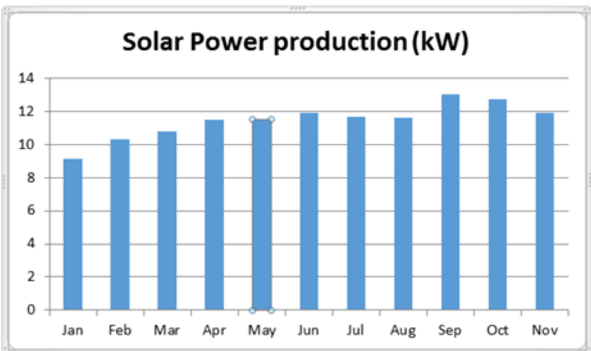

Figure 5: Monthly power output from PV array

6.2 Wind Power Output

Wind mill has a promising future as Leh Ladakh region. In this study the wind mill is included for examining the feasibility of wind mill and also it enhances the reliability of the system. For economical reason the capacity installation of wind mill is restricted at 2 kW. AIR SWX type wind mill is included in the study. It operates for 4,347 hours with capacity factor of 2.06%. The throughout capacity is 1728 kWh. The figure depicts the variation in the power output of windmill with different month

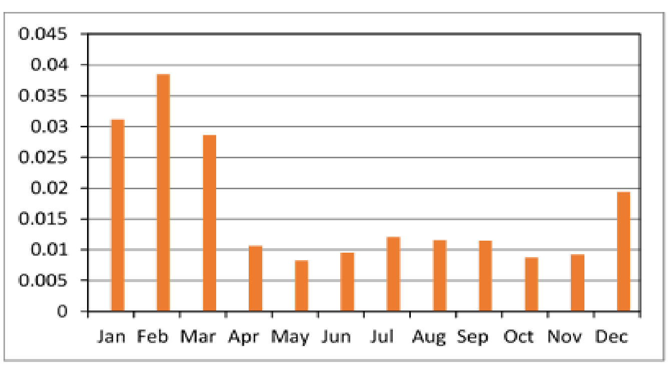

Fig. 6: Wind mill power output

6.3 Grid Supply

The grid execution was implemented in view to observe the impact of such integration. The grid also eliminates the need for placing the battery bank in the system. The hybrid system is connected with the grid through net metering process. Both the energy purchase from the grid during the production of unmet load and sold to grid during production of excess power is estimated and then the difference in power purchase and sold is calculated to do the needful financial exchange. The grid integration will ensure the supply stability whereas hybrid integration ensures the reduction of environmental pollutants

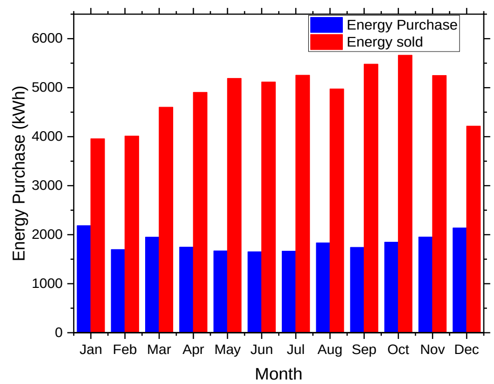

Figure 7: Grid energy purchase and sold

6.4 Daily Energy Production and Load Demand

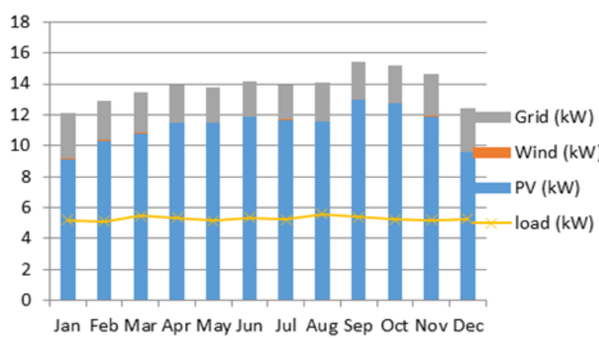

Figure 8: Daily Energy Production and Load Demand

The daily average power production is shown in blue; wind energy production shown in red and grid are shown in grey color stack. After meeting the local load demand the power is supplied to the grid for selling it a pre-defined price to generate some income out of the project.

6.5 Hourly Energy Balance of the Proposed System

An example of the hourly simulation result during one typical days is illustrated in the below figure 9 to analyze the energy balance of the proposed system. It is obvious that the available power output is first used to cover the local power demand. The grid established only when the energy balance from the hybrid and load does not match. In case of short fall of energy to meet the load unmet portion of energy is taken from the grid at the

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price fixed previously and in case of surplus of energy after meeting the load demand the excess energy is sold to the grid.

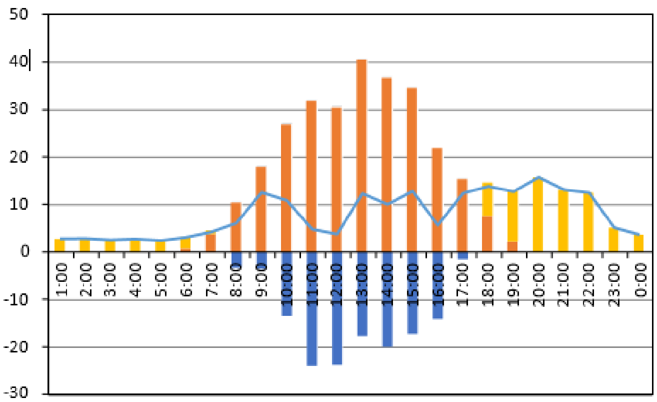

Figure 9: Hourly energy balance

6.6 Sensitivity Analysis

The cost reduction and technological development of renewable energy systems in recent years has been encouraging in Indian context. Hence, it is presumed in the study that the system cost is likely to decrease in future. In order to simulate the declining cost for the long term analysis; a 20% reduction in PV and Inverter costs and wind mill has been incorporated in the estimation. When merely the PV cost is reduced by the by 20%, the total NPC and COE are reduced significantly. The levelised cost of energy reduced to INR 3.94, which shown a reduction of 25%. In all these supposition, operating cost is found to be increased a bit with renewable fraction and capacity shortage of 0.82 and 0 respectively.

6.7 Economic Analysis

In below table 1 shows the overall optimization result of the hybrid system which is generated in the HOMER software. Each row in the table represents a viable system configuration. The first 4 column shows icon, next four column indicate number or size of each component, the next five column shows key simulation results, such as capital cost of the system, operating cost, Net present cost, levelized cost of COE and renewable fraction. The optimal configuration is the one having lowest NPC which comprises of 1000kW of grid, 50 kWP PV,2 kW of SW AIRX wind mill, 30 kW converter. The 7 COE is found to be 5.307/kWh and100% renewable fraction. There is a chance of income generator of INR 102,353 per year.

Table 1: Optimization result of Grid/PV/Wind hybrid system

PV (kW)	AIR	Conv. (kW)	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.
50	2	30	1000	$ 4,453,280	-102,353	$ 3,144,862	5.307	0.82
50	2	28	1000	$ 4,439,728	-91,928	$ 3,264,584	5.509	0.82
50	3	30	1000	$ 4,553,280	-89,940	$ 3,403,548	5.744	0.82
50	2	25	1000	$ 4,419,400	-72,737	$ 3,489,574	5.889	0.82
60	2	30	1000	$ 5,263,280	-136,427	$ 3,519,285	5.939	0.85
50	3	28	1000	$ 4,539,728	-79,503	$ 3,523,408	5.946	0.82
50	4	30	1000	$ 4,653,280	-77,526	$ 3,662,235	6.180	0.82
60	2	28	1000	$ 5,249,728	-121,273	$ 3,699,452	6.243	0.85

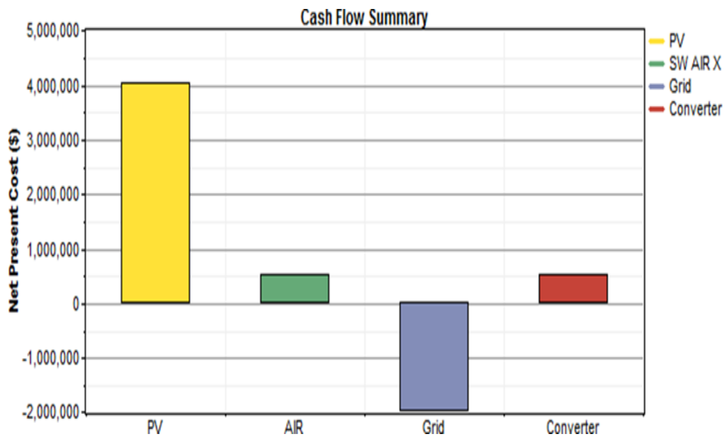

Figure 10: Cash flow outline of the project

To determine NPC, it performs a cash flow analysis which shown in figure 10, it reveals the cash flow outline based on the components selected on the system. PV shares the maximum capital cost. In below table 2, NPC summary of the most optimized model. Grid connection shows the income generation.

Table 2: Net Present Cost

Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
PV	4,050,000	0	0	0	0	4,050,000
SW AIR X	200,000	83,453	255,667	0	-15,533	523,587
Grid	0	0	-1,960,900	0	0	-1,960,900
Converter	203,280	84,822	259,860	0	-15,788	532,174
System	4,453,280	168,275	-1,445,372	0	-31,321	3,144,862

The yearly cash flow throughout the systems life span is depicted in the below figure 11. Each bar in the graph represents either a total inflow or total outflow of cash for a single year. The first bar, for year zero, shows the capital cost of the system. A negative value represents an outflow (expenditure) due to equipment replacement, or O&M. Possible replacement of converter and wind mill in the 15th year. A positive value represents inflow, which may be income from the salvage value of the equipment's at the end of the project life time.

Table 3: Annualized cost

Component	Capital ($/yr)	Replacement ($/yr)	O&M ($/yr)	Fuel ($/yr)	Salvage ($/yr)	Total ($/yr)
PV	316,818	0	0	0	0	316,818
SW AIR X	15,645	6,528	20,000	0	-1,215	40,958
Grid	0	0	-153,395	0	0	-153,395
Converter	15,902	6,635	20,328	0	-1,235	41,630
System	348,365	13,164	-113,067	0	-2,450	246,012

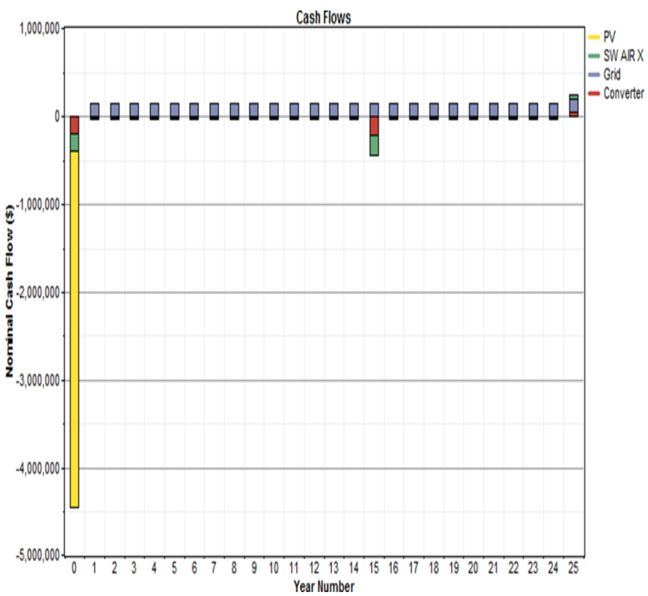

Figure 11: Cash flow information of the scheme

6.8 Performance Summary of Different System Components

Table 4: Summary of different system components

Parameters	Value	Unit
1. PV Array		
Rated Capacity	50	kW
Mean output	11.3	kW
Mean output	271	kWh/d
Capacity factor	22.6	%
Total production	98,968	kWh/year
Minimum output	0	kW
Maximum output	49.7	kW
PV penetration	133	%
Hours of operaton	4,382	hour/year
Levelized cost	3.20	$/kWh
2. IAR SWX		
Total Rated Capacity	0.800	kW
Mean output	0.02	kW
Capacity factor	2.06	%
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	284	$/kWh
3. Converter		
Capacity	30	kW
Mean output	9.5	kW
Minimum output	0	kW
Maximum output	30.0	kW
Capacity factor	31.5	%
Hours of operation	6,122	hours/year
Energy in	92,106	kWh/year
Energy out	82,895	kWh/year
Losses	9,211	kWh/year
4. Grid		
Energy Purchased	22,071	kWh
Energy Sold	58,611	kWh
Net Energy (Sold)	36,540	kWh
Peak Demand	16	kW
Energy Charge (Income Generated)	-153,395	$

7. CONCLUSION

In this study the hybrid PV-Wind-Grid system is examined. The results are showing promising. It concludes that with the integration of grid, the power output of the system increases, the schemes employed in the study are also complementary in nature, the capacity shortage is 0 % which also increases reliability of the scheme, the levelized cost of energy is 5.37 INR/kWh, with a capital gain of INR 1,02,353 per year, proposed scheme is also having huge savings in pollutants and hence ecofriendly system which does not disturb the existing eco system.

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