Viability study of on-grid PV/Wind integrated System

Sakina Bano[1], Satish Saini[2]

Department of Electrical Engineering, RIMT Univeristy, Punjab

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Abstract –

Rural electrification is a challenge in most of the developing nations. In India although there is enormous development in electrification though various schemes of Union government in recent years, still some villages are there where the supply reliability is a concern. During this power outage various activities related to electricity comes to halt and affected not only the comfort of people but also the economic productivity. This paper examines feasibility and economic viability of integrated system of PV/Wind with unreliable grid for maintaining the supply reliability. The study aims to provide cost-competitive, eco-friendly and continuous power supply. Based on the load pattern variation, meteorological data of the study area and input of grid energy, a model is synthesized using HOMER software. Then a techno-economic analysis was carried out. Results showed that the integrated model is technically and economically feasible with positive impact on the environment. The cost of energy for the proposed model is INR 5.992 with a renewable penetration of 0.9.

INTRODUCTION

India is highly dependenton conventional power generation sources. More than 60% of electricity generation in India is done by fossil fuel-powered thermal power. The generation of electricity from fossil fuels such as coal poses environmental challenges and its rapid depletion in the next few decades will be a challenge to electricity generation. Renewable energy sources (wind, solar, biomass, etc.) have proven to be an attractive option to replace currently used energy production methods in the near future [1].

To achieve climate goals, low-carbon energy technologies, such as solar power, need to be prioritized and deployed at scale. India has done an outstanding job in implementing renewable energy installations. As of March 31, 2021, the total installed solar capacity is 40.1 GW and the Indian government has stated its ambition to increase solar capacity to 100 GW by 2022 (Status, Energy). solar energy, Ministry of New and Renewable Energy (MNRE), Government of India, n.d.) [2].

India ranks 4th in the world in wind power generation afterChina, USA and Germany. Wind energy in India has potential capacity of 102 GW at a tower height of 80 m [3].The efficient production of wind power projects depends on many factors such as wind speed (m/s), wind energy density (W/m2), the availability of website, etc. The National Institute of Wind Energy (NIWE) was established by MNRE in Chennai, as an autonomous research and development center,conduct wind assessment programs nation wide and have successfully plotted wind energy maps of India at different altitudes.

LITERATURE REVIEW

Kandpal et al (2010) present an economic-technical comparison of two options, particularly solar space and microgrids, to facilitate a choice somewhere between them, based on annual life cycle expenditure (ALCC) [4].Bulm et.al (2013) calculates the Levilised Cost of ELectricity (LCOE) from solar photovoltaic (solar PV) and microhydro systems in the village, and compares them with conventional diesel treatment. For solar photovoltaics, consider special product configurations that include minimal back-up supply as well as a hybrid approach. Last but not least, calculate the cost of reducing CO2 emissions as well as the potential for reduction. Solar photovoltaic solutions increase their competitiveness due to the distance from the village grid and once supply reduction is applied then redundancy will be applied [5]. Bajpai et al. (2012) review the investigation of device size, optimization, electrical control and component modeling of an renewable energy hybrid approach. Also discussed dvances in research in hybrid energy modeling (photovoltaic devices), backup power systems (fuel cells, batteries, super capacitors and diesel generators), energy generation products (MPPT converter, Buck/Boost, battery charger) as well as methods to manage the energy flows [6]. PK Chaurasiya et al. (2019) show that India is indeed endowed with an unlimited amount of energy in general resources and wind energy in particular. Assessing the possibility of wind potential to replace the country's energy situation is crucial for the development [7]. S. Sharma et al. (2019) found wind energy was used for different purposes in ancient times. Today, wind energy is used to generate electricity. Wind power is indeed one of the cleanest sources of energy and India also has huge wind energy potential (102 GW typically at 80m and 302 GW at 100m) [8]. T. Sarkar et al (2019) stated electricity is the basic necessity of life, however there are places specially in rural areas which do not have continuous supply due to inadequate transmission infrastructure and distribution methods. However, these sources can be complemented by integrating with the SPV and other renewable energy sources. In this paper, the unique combination of solar, wind, biomass and vanadium redox current battery (VRFB) storage integrated into hybrid microgrids is truly demonstrated. The model is optimized by the HOMER simulation software [9]. V. Kumar et al (2016) presents an assessment of power quality and network integration issues related to the direct integration of renewable power systems into the national grid. In this paper, recent trends for high-performance electronics for integrating wind and photovoltaic (PV) generators are also presented [10].

METHDOLOGY USED

The Hybrid Optimized Model for Electric Renewables (HOMER) [11], a simulation technology based on renewable energy developed by the National Renewable Energy Laboratory (NREL) of the United States, used for simulation in the study. The software is widely used in many countries to simulate the model to determine the feasibility and feasibility of the model before deployment. The software can simulate different renewable and non-renewable sources and can manage the time step to get simulation with desired duration. The software iterates the given combinations to find the optimal combination, the sensitivity analysis ensures project safety. The software has many outstanding advantages. The simulation offers many variations, especially the financial variant, which makes the program more attractive [12].

ENERGY BALANCE EQUATION[13]

The equations governing the energy balance of the different configurations of systems, can be written in the following way, where Ein is the Energy IN the System and Euse is the Energy Used:

$$E_{in} = E_A + E_{BU} + E_{FUN} + E_{FSN} \quad (1)$$

$$E_{use} = E_L + E_{TUN} + E_{TSN} \quad (2)$$

where EFUN and ETUN are, respectively, the Net Energy FROM and To the Utility, and EFSN and ETSN are, respectively, the Net Energy FROM and To the Storage Unit, as defined in the IEC-61724 Standard. EA, EBU, the net energy from Array generation and battery respectively and EL is the load in the system.

MODELING OF PV POWER GENERATION

Photovoltaic modeling is performed to calculate the number and size of photovoltaic modules. The number of modules depends on various factors such as load to be serviced, rated voltage and current. The model used [8,9]. Shockley diode equation is used to express relation between voltage and current of PV cell, expressed as

$$I = N_p I_{ph} - N_p I_0 \left(e^{\frac{1}{V_t}\left(\frac{V}{N_s}+\frac{I_{RS}}{N_p}\right)} - 1 \right) - \frac{N_p}{R_p} \quad (3)$$

Iph is the photo current in A; I0 is the saturation current od diode in A; Rs is the series resistance and Rp is the parallel resistance in Ω; Vt= nKT/q is the thermal voltage of diode; n is the diode ideality factor; T is temperature in Kelvin; K is Boltzmann’s constant and q is the charge: Np is the module connected in parallel and Ns denotes modules in series

The Power equation of PV array is expressed as

$$P=VI= N_p I_{ph} V - N_p I_0 V \left(e^{\frac{1}{V_t}\left(\frac{V}{N_s}+\frac{I_{RS}}{N_p}\right)} - 1 \right) - \frac{N_p}{R_p} V \left(\frac{V}{N_s} + \frac{I_{RS}}{N_p} \right) \quad (4)$$

The important parameters are calculated under STC. The parameters like Iph, I0, Vt, Rs& Rp are specified by the manufacturer. The process discussed in [10] like Iph STC, I0 STC, Vt STC, Rs STC & Rp STC can be calculated as

$$I_{ph} = I_{ph,STC}[1 + \alpha I_{sc}(T - T_{STC})]\frac{G}{G_{STC}} \quad (5)$$

$$I_0 = I_{0,STC}\left(\frac{T}{T_{STC}}\right)^3 \exp\left(\frac{E_{g,STC}}{kT_{STC}} - \frac{E_g}{kT}\right) \quad (6)$$

$$P_{PV} = Y_{PV}f_{PV}\left(\frac{\overline{G}_T}{\overline{G}_{T,STC}}\right)[1 + \alpha_P(T_c - T_{c,STC})] \quad (7)$$

$$V_t = V_{t,STC}\frac{T}{T_{STC}} \quad (8)$$

$$R_p = \frac{R_{p,STC}}{G/G_{STC}} \quad (9)$$

$$R_{sh} = R_{sh,STC} + 3 \times R_{sh,STC}e^{-5.5/G_{STC}} \quad (10)$$

$$T = T_m + \frac{G}{G_{STC}}\Delta T \quad (11)$$

G is the actual radiation incident of PV module; Eg is the band gap in eV; Tm is the temperature of back surface of the module which affects the overall performance of the module; DT denotes the difference in temperature between cell and back surface.

MODELING OF WIND ENERGY

HOMER synthesizes the wind data which are manually entered after collection[11]. Hourly is capable of producing hourly simulation data, which is organized in a monthly fashion

Tip speed ratio

It is the ratio between the tip speed of the blade and the speed of the wind. As the air passes through the propeller, it encounters turbulence afterwards. The next wing will come hen the turbulent air has completely disappeared to take full advantage of the power from the wind. The maximum speed ratio adjusted the propellers to not pass through in turbulent air [11].

$$\text{Tipspeedratio} = \frac{\text{Tipspeedofblade}}{\text{windspeed}} \quad (15)$$

Betz limit is fixed at 59%, and the height of the wind mill installation tower is 40 feet.

DESCRIPTION OF THIS SYSTEM

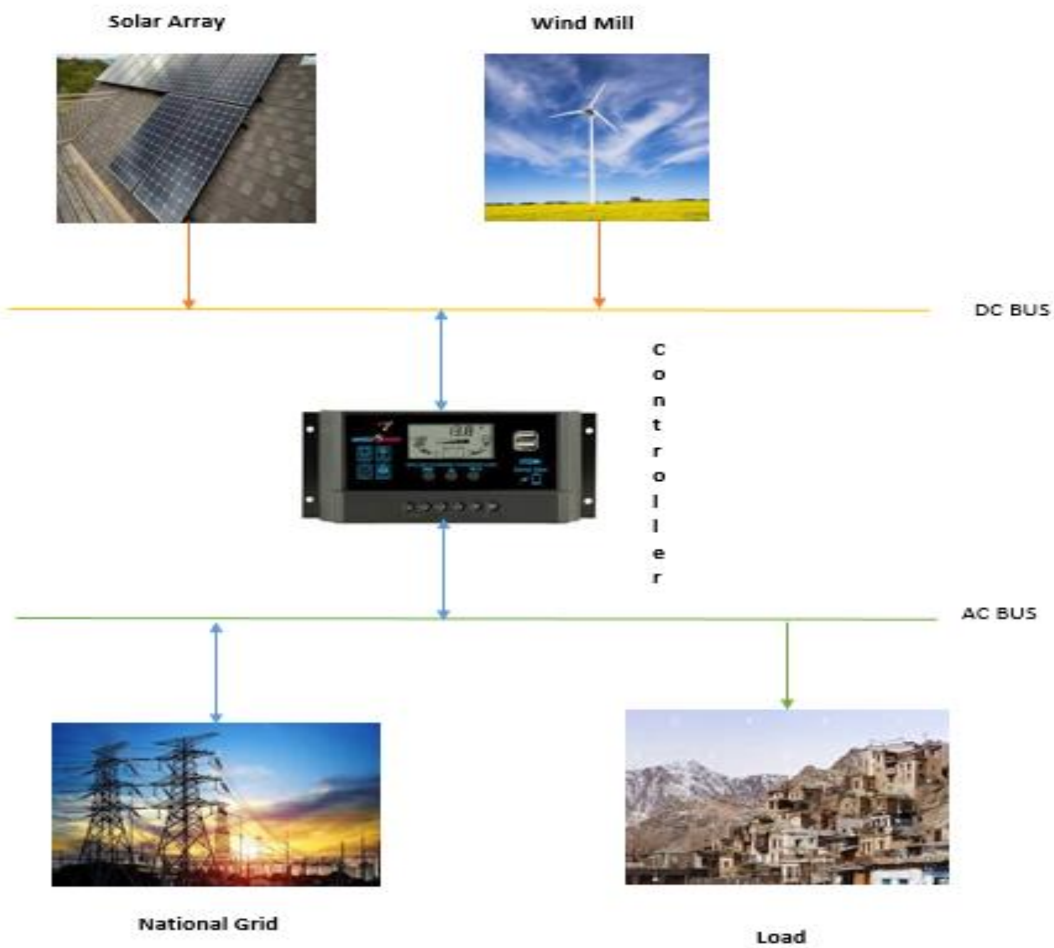

Fig 1 Proposed Model

The proposed method required in this analysis has generator (photovoltaic array, national grid and wind turbine), one end-user (one controller and intended load). The model is conceived in grid integrated mode. The analysis is actually conceived with domestic load of Leh Ladakh.

The PV-Wind-Grid integrated system working can be described as follows. The SPV make the power required by the load throughout day time along with the windmill. Of season of additional power yield the imperativeness will be proposed to the grid with a pre fixed cost and through deficiency of energy it very well may be purchased utilizing the same grid. Net meter estimates the differentiation and furthermore shows the financial adjustment needed on monthly basis Along these lines, a reasonable and dependable power source will be guaranteed for round the clock. The main parts of the method is actually PV array, wind mill, national grid link, Balance of the system as inverter ,converter as well as control station.

LOAD PROFILE

The proposed system is capable to serve a daily load of 62kWh/day with a peak demand of 8.4 kW. However the loads were presumed depending upon the population present in that habitat. It is expected that the power consumption may be increase in near future. The scheme is mainly designed to meet domestic or household demands. The HOMER synthesizes the load to provide the required pattern. As well as ease of use, seasonal shuffling of demand is not taken into account.

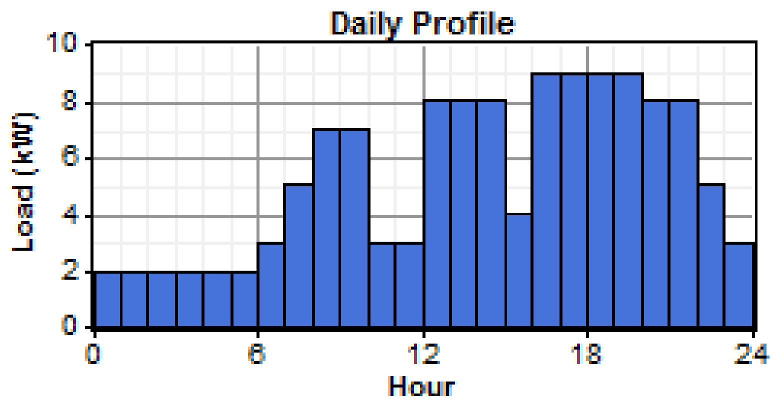

Fig 2 Hourly load

SOLAR POWER RESOURCE

For the proposed model, SPV is one of the major sources of energy. With the improvement of technology, the production of photovoltaic energy is increasing more and more. The production of electrical energy in a photovoltaic installation is in fact determined by the weather at the installation site. The typical Indian sunshine difference is actually between 4 and 7 kWh/m2/day. The analysis was actually done at latitude 34.15 degrees and longitude 77.57 degrees. And also during these recommended location months, typical daily sunshine was found to be 5.887 kWh/m2/day with a clarity index of 0.702. PV array installed electrical capacity 50 kWP.

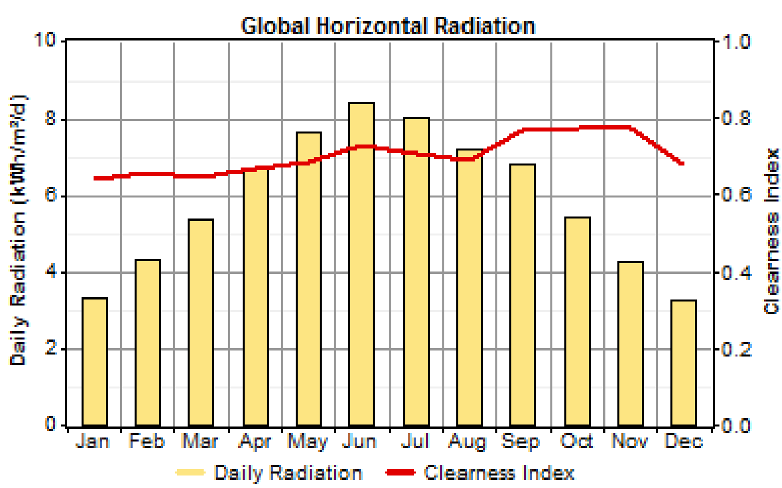

Fig. 3 Solar energy resources

WIND RESOURCE

The model integrated a wind mill too as a primary source of energy, however the air pressure at the installation site is less. For this analysis, the wind turbine is kept for testing purposes only, so the size of this turbine was practically limited to around 2 kW, the SW AIRX aerator was actually chosen for this purpose. The life of this windmill is actually 15 years. The actual average annual wind speed is 3.817 m/s on the proposed site.

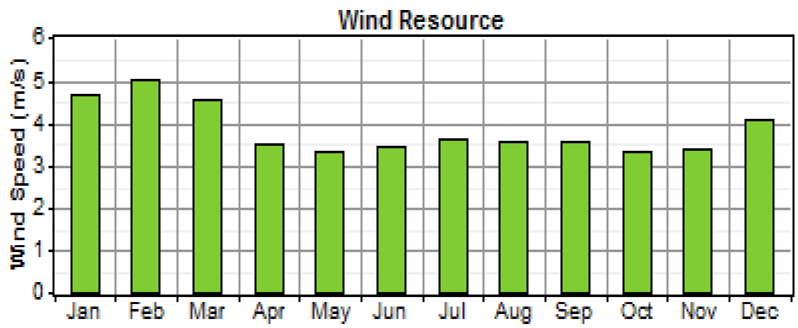

Fig. 4 Wind energy resources

NATIONAL GRID

For convenience of use, the price as well as the purchase and sale of electricity close to the grid in the program have been integrated. Since the grid already exists, no additional prices are actually included. The grid purchase energy in the cross product is INR 4.50/kWh and is offered at INR 5.00/kWh. The repurchase agreement is recognized as in this case.

RESULT AND ANALYSIS

SOLAR PV MONTHLY POWER PRODUCTION

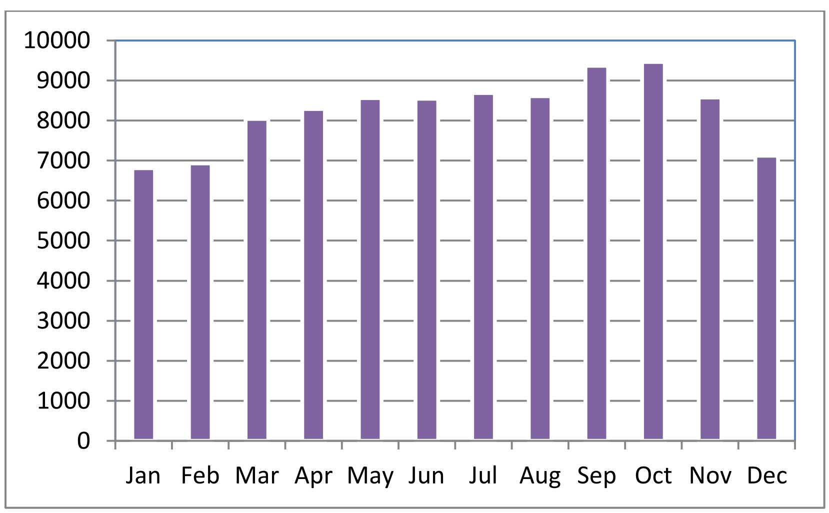

Fig 5 Monthly power output from PV array

The monthly variation in photovoltaic generator production is shown in the figure below. It is found that the output power of the photovoltaic generator is sufficient throughout the year and peaks in September and November. Thus, throughout the year, the photovoltaic network can generate a reasonable amount of energy. Depending on the climatic conditions, the output capacity of the photovoltaic generator is estimated at 98,968 kWh/year.

WIND OUTPUT

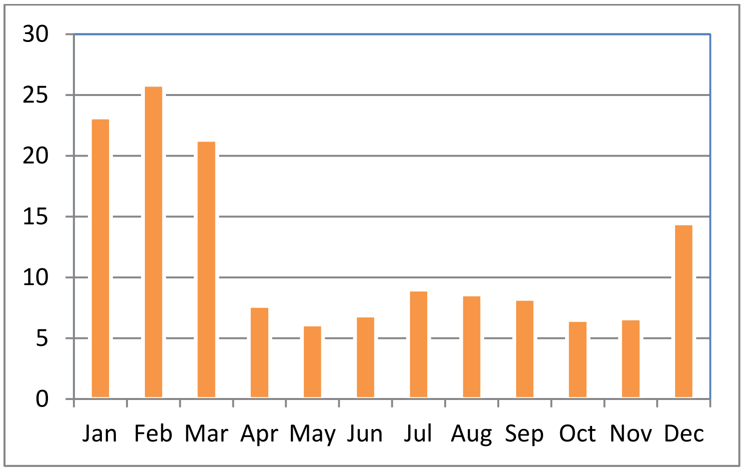

Fig. 6 Wind mill power output

Wind turbines have a promising future in the Leh Ladakh region. In this study, wind turbines are included to test the feasibility of wind turbines and it also improves system reliability. For economic reasons, the installed capacity of the wind turbine is limited to 2 kW. Wind turbines of the type AIR SWX were included in the study. It operated for 4,347 hours with a power factor of 2.06%. Total energy production is 144 kWh. The figure illustrates the variation of windmill output power over different months.

GRID SUPPLY

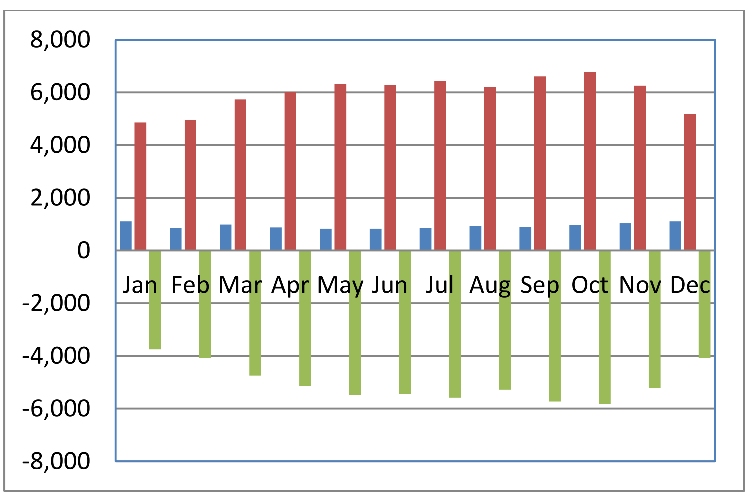

Fig. 7 Grid energy purchase and sold

Grid is integrated with the existing structure to study the behaviors of the combined operation. In Grid –tied version the battery requirement is eliminated. Net-meter is placed to measure the energy exchange between the grid and system. Financial settlement is done on the basis of difference of energy in and out from the grid to the hybrid model. Supply stability can be maintained by the grid integration. The blue bar displays energy sold to the grid while the red bar shows the energy purchase form the grid the green bar shows the net purchase form the grid, as the proposed model sold more energy than it purchase so the net purchase is shown in negative axis.

ENERGY DEMAND AND SUPPLY

The below diagram explains the energy production of the scheme against the demand of energy in different months. The green bar represents the energy of grid, the blue bar represents the energy from the SPV and the red bar represents the energy production of the wind turbine. The navy line represents load demand of the proposed model, for which the system is designed.

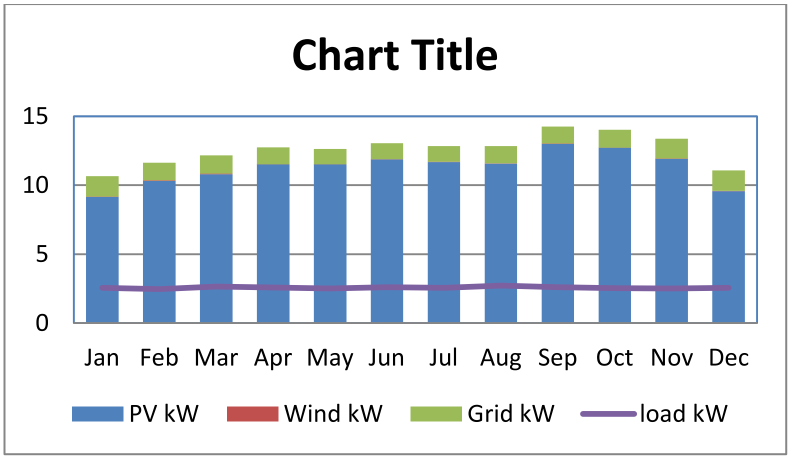

Fig. 8 Daily energy production and load demand

EMISSION FROM THE SYSTEM

The below figure delineates the emission level of the model. Being one of the noble idea of the scheme, it is observed that by the utilize of hybrid energy rather than non-renewable source the proposed scheme able to reduce 38,157 kg of carbon dioxide, 165 kg of sulfur dioxide and 80.9 kg of nitrogen oxide per year. The model appears a ideal combination to reduce a huge sum amount sum Synonyms of carbon foot print and other major toxins capable for worldwide warming.

Table 1 Emission from the system

Pollutants	Emissions (kg/yr)
Carbon dioxide	-38,157
Carbon monoxide	0
Unburned hydrocarbons	0
Particulate matter	0
Sulfur dioxide	-165
Nitrogen oxides	-80.9

HOURLY ENERGY BALANCE OF THE PROPOSED SYSTEM

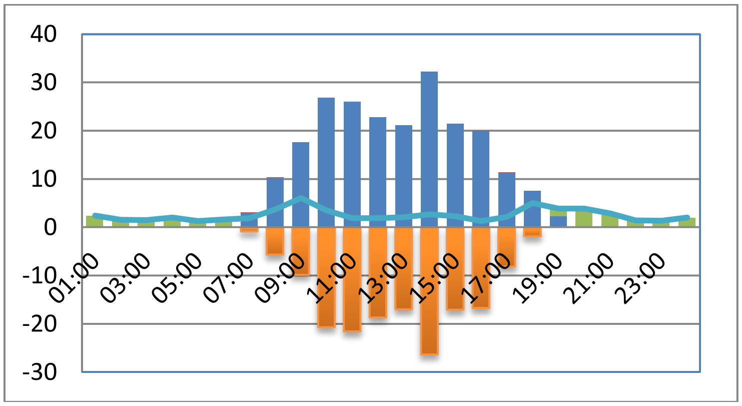

Fig 9 Hourly energy balance

For analyzing the energy flow in the system an example of a typical day is shown in the above diagram. The system is so designed that the power generated will be utilized serve the load of the system at first instance. During either surplus of deficit of energy grid comes into the picture. Both the provision of energy supply to the grid and energy purchase from the grid is established to maintain the energy equilibrium. Primary load shown in navy blue line, PV power in blue bar, orange bar depicts the windmill output. Grid sale and purchase are shown by orange and green bar respectively.

ECONOMIC ANALYSIS

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	-215,000	$ 1,704,860	5.922	0.90
50	2	28	1000	$ 4,439,728	-204,574	$ 1,824,581	6.338	0.90
50	3	30	1000	$ 4,553,280	-202,584	$ 1,963,571	6.821	0.90
50	2	25	1000	$ 4,419,400	-185,384	$ 2,049,572	7.119	0.90
60	2	30	1000	$ 5,263,280	-248,889	$ 2,081,645	7.231	0.91
50	3	28	1000	$ 4,539,728	-192,148	$ 2,083,430	7.237	0.90
50	4	30	1000	$ 4,653,280	-190,169	$ 2,222,283	7.719	0.90
60	2	28	1000	$ 5,249,728	-233,735	$ 2,261,812	7.857	0.91
50	3	25	1000	$ 4,519,400	-172,945	$ 2,308,584	8.019	0.90

Fig 11 Optimization result of the proposed system

The 1st fig. 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 COE is found to be 5.922/kWh and with no shortage of capacity. There is a chance of income generator of INR 215,000 per year.

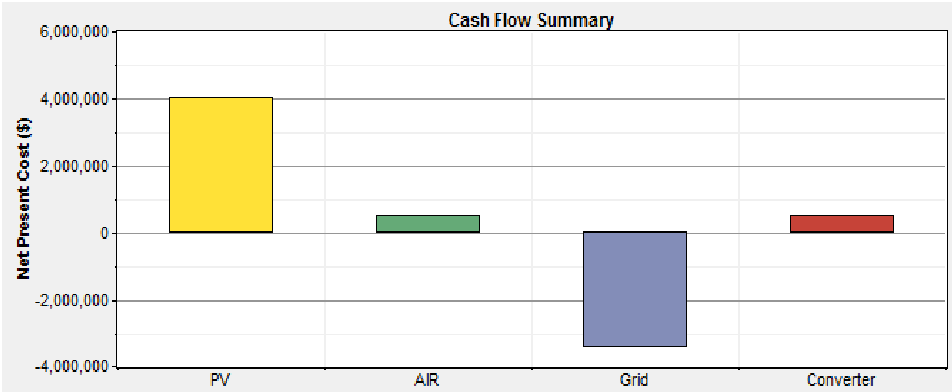

Fig.12 Cash flow outline of the project

PERFORMANCE SUMMARY OF DIFFERENT SYSTEM COMPONENTS

Table 2

Parameters	Value	Unit
PV array		
Rated capacity	50.0	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	439	%
Hours of operation	4,382	hour/year
Levelized cost	3.20	$/kWh
IAR SWX		
Total rated capacity	0.800	kW
Mean output	0.02	kW
Capacity factor	2.06	%
Total production	144	kWh/yr
Minimum output	0.00	kW
Maximum output	0.21	kW
Wind penetration	0.641	%
Hours of operation	4,347	Hr
Levilized cost	284	$/kWh

Converter		
Capacity	30.0	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
Grid		
Energy purchased	11,287	kWh
Energy sold	71,661	kWh
Net energy (sold)	60,374	kWh
Peak Demand	8	kW
Energy charge (income generated)	-266,041	$

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 levilised cost of energy is 5.992 INR/kWh, with a capital gain of INR 2,15,000per year, proposed scheme is also having huge savings in pollutants and hence eco friendly system and hence recommended.

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